SWINE CAFO ODORS:
Guidance for Environmental Impact Assessment

Region 6
U.S. Environmental Protection Agency

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1. INTRODUCTION AND SUMMARY

Introduction

Regulatory perspective and acronyms. Concentrated Animal Feeding Operations (CAFOs) concentrate livestock production in buildings or feedlots, producing large volumes of waste water. New or expanding CAFOs must apply for permit coverage under the U.S. Environmental Protection Agency's (EPA's) National Pollutant Discharge Elimination System (NPDES) for waste water. EPA must prepare environmental assessments (EAs) or environmental impact statements (EISs), as required by the National Environmental Policy Act (NEPA), to assess the potential for impacts. EAs or EISs utilize information submitted by permit applicants in their Environmental Information Documents (EIDs).

CAFOs, waste water, and odors. Waste water handling during animal housing, storage, treatment, and land application can cause odors which can impact neighbors if CAFOs are not managed to minimize odor production. Complaints by neighbors may lead to legal actions seeking court injunctions against EPA and others, including the applicants. To minimize odor impacts and minimize legal conflicts, EPA's EAs need to consider potential odor pollution impacts from waste water handling and discharge. However, applicants' EIDs often contain little information on potential odor impacts, and if information is available the connection between management practices and odor may not be readily apparent to the permit reviewer.

Purpose and scope. This report is intended to address the preceding problem by helping those evaluating swine CAFOs to understand how swine odors are generated, what their impacts can be, and how proposed CAFOs may or may not be designed to abate potential odor impacts. It is also hoped that this report may be useful to those designing and operating CAFOs, by providing basic information and a checklist of potential swine odor abatement measures. The report's scope is limited to the use of existing literature to summarize the current understanding of swine odors.

In addition to this introduction and summary, this report considers the following:

1. sources of odors from swine production facilities;
2. potential impacts of swine odors;
3. methods and technology to measure and predict odor impacts;
4. CAFO design and management practices for odor reduction;
5. odor abatement additives;
6. a checklist of abatement measures.

Summary of most critical elements

Sources. Most notable about odor sources is that there are so many compounds potentially involved. Compounds may have their own odors, or they may combine with other compounds to produce different odors. The main classes of odor-causing chemicals are: volatile fatty acids, indols and phenols, ammonia and volatile amines, and volatile sulfur-containing compounds. Offensive odors can be generated by several parts of a CAFO, especially: 1) confinement buildings and open feedlots; 2) manure storage and treatment; and 3) land application of wastes. For example, dust can carry odors from confinement building exhausts, and aerosols can carry odors from lagoons and from land application sprinklers.

Impacts. Beyond CAFO employees and their families living on site, swine odors impact CAFO neighbors. Especially sensitive receptors include schools, hospitals and persons with pre-existing respiratory conditions. There is minimal documentation of specific impacts to neighbors from specific chemicals in swine odor, though such studies are underway. Generally, swine odors may potentially impact quality of life at the individual and community levels, by interfering with normal social functions and, depending on severity of the odor and sensitivity of the individual, by affecting mood and physical well being (e.g., through nausea, loss of sleep, and resulting physical susceptibility).

Measurement. It is possible to measure some specific odor-causing chemicals. However, a measured value of ammonia, for example, may have little to do with an actual perceived odor at a downwind location, which is more likely to result from a combination of chemicals. As a result, odors are often measured using human panelists fitted with devices (olfactometers) which control panelists' intake of air in order to provide a consensus of sensory impact. Such field measurements form the basis for property-line odor regulations in several states and localities. Another way to measure odor is to use mathematical models to predict odor potential based on environmental characteristics such as terrain and wind speed. Modeling has not been developed to the point where compliance standards can be set.

Management. Management is the key to controlling odors. Odor-reducing management practices are available for all aspects of a CAFO, including site selection, building design, waste processing and disposal, and daily operation and maintenance. The evaluation checklist provided in this report is an effort to show which management practices are most likely to control odors. Often, good waste water management and control of odors go hand in hand, in that a clean, efficient CAFO produces less odor and more income at the same time.

Additives. It may be possible to reduce odors by modifying animal diet and waste water treatment processes. Most feed and waste additives are commercial, odorant-specific, expensive, and require persistence. Their uses may best address short-term problems. The limited capability of additives to control odors makes it especially important that effective engineering and management practices be part of the original project design.

Research. A number of research needs are noted in this report. Following is a list of short-term research needs, not prioritized, from Safley (1994).

- Evaluation and classification of commercial products.
- Definition of microbiology in anaerobic systems.
- Evaluation of impact of nutrition modification.
- Development of on-site monitoring equipment.
- Development and evaluation of waste management systems emphasizing odor control.
- Development of predictive models to estimate potential odor strength, duration and dispersion as a function of meteorology and topography.
- Development of cost-effective scrubbers for ventilation equipment.
- Understanding the "true" impact of odor on humans.

From a longer-term perspective, a priority should be development of databases and accurate models that lead to reliable design criteria or guidelines on separation distances required for site selection and for land spreading or irrigation of manure, separated solids or lagoon effluent.

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Peer review of a draft of this report was provided by Dr. John M. Sweeten, Texas Agricultural Experiment Station, Texas A&M University System, Amarillo, TX. Review by Dr. Sweeten does not constitute endorsement by him or the State of Texas of this work product or any commercial products mentioned herein. Any errors or misunderstandings are those of the authors; corrections and additions would be appreciated and be applied to any further edition.

2. SOURCES OF SWINE ODOR

Odor sources and transport at CAFOs

Odors from swine operations are complex mixtures of gases, vapors, and dust. Odorous mixtures vary with location, the size and type of swine operation, production practices, season, temperature, humidity, time of day, and wind speed and direction. Smith (1995) provides the following conceptual model from odor generation to reception.

GENERATION ⇒	EMISSION ⇒	DISPERSION ⇒	DETECTION ⇒	RECEPTION
Ration type	Wind speed	Wind speed, direction	Averaging period	Background odors
Manure depth	Surface roughness	Atmospheric stability	Fluctuations	Lifestyle expectations
Moisture content	Atmospheric stability	Surface roughness	Background odors	Social background
Volatile solids	Management	Topography	Odorant mixture	Non-odor concerns
Temperature & pH	Surface moisture content	Mixing height	Individual threshold	

Odorous gases and vapors are often the intermediate and final products of anaerobically decomposing manure - that is, manure degraded by bacteria that does not use oxygen. Anaerobic decomposition produces the familiar smell of ammonia, the "rotten egg" odor of hydrogen sulfide gas, and odors from volatile fatty acids, which people often find more offensive than either ammonia or hydrogen sulfide (Swine Odor Task Force, 1995).

Some 168 odorous compounds have been identified in swine waste (Veenhuizen, 1996). These compounds result from natural biological reactions and include organic acids, alcohols, aldehydes, fixed gases, carbonyls, esters, amines, sulfides, mercaptans, nitrogen heterocycles, and phenol. Four-methylphenol, also called paracresol, is a predominant metabolite which provides swine slurry its characteristic creosote or disinfectant-type odor (Yokoyama, 1994).

Mackie (1994) divided odorous compounds from swine manure into 4 chemical classes:

1. volatile fatty acids (including isobutyric, 2-methylbutyric, isovaleric, valeric, caproic, and capric acids);

2. indols and phenols (including indole, skatole, cresol, and 4-ethylphenol);

3. ammonia and volatile amines (including putrescine, cadaverine, and aliphatic amines such as methylamine and ethylamine);

4. volatile sulfur-containing compounds (e.g., sulfide, methyl- and ethyl-mercaptans).

All of these compounds are metabolic end products of anaerobic bacteria. With so many compounds and environmental variables, it is often difficult to determine which compound - or combination of compounds - is giving offense.

Engineering and management options have often focused on ammonia emissions as an indicator of successful odor control. However, not all researchers agree that ammonia levels accurately indicate odor levels, especially with increasing distance from the source since ammonia, unlike hydrogen sulfide, is lighter than air. For example,

- Schulte et al (1985) linked high levels of odor emission to high ammonia volatilization;

- Liu et al (1993) found that ammonia levels are not good indicators of odor threshold levels in swine buildings;

- According to Oldenburg (1989), it is a well known fact that high odor concentrations in waste air does not mean that ammonia concentrations are high as well and vice versa;

- Miner (1995) found that, generally, a ventilation and waste handling system that controls the ammonia level in a building will also result in lower odor levels.

The majority of swine CAFO odors may be carried on airborne particulates such as dust or aerosol (Miner, 1995; Veenhuizen, 1996). Odor nuisance is often due to poor housekeeping practices and problems associated with manure management practices (ASAE, 1994).

It is generally accepted that there are three main sources of odor at swine CAFOs (Veenhuizen, 1996; NPPC, 1996; Swine Odor Task Force, 1995): 1) confinement buildings and open feedlots; 2) manure storage and treatment; and 3) land application.

Confinement buildings and open feedlots

Fresh manure has a less objectionable odor than decomposing manure (Sweeten and Rodriguez-Akabani, 1994). If manure accumulates in buildings and feedlots for longer than 3 to 5 days, more and increasingly offensive odors from anaerobic decomposition will result. Ammonia emissions from swine manure peaks at 3 days and again at 21 days (Veenhuizen, 1996). Carcass management is a possible odor source in both confinement buildings and open feedlots; odors can be released from carcasses once decomposition begins (Swine Odor Task Force, 1995).

Confinement buildings have a high odor potential due to high stocking densities of animals, a large inventory of manure in storage, and a limited rate of air exchange (Sweeten and Rodriguez-Akabani, 1994). A warm, moist environment intensifies odors, though temperature and humidity can be controlled by air conditioning. High dust concentrations in confinement buildings will generally translate to increased odors in exhaust air, resulting in odor transmission. Dust is influenced by animal activity, the rate of air exchange, and the type of feed and feed delivery system used (NPPC, 1996). Sources of dust in livestock buildings are feed (80-90%), bedding material (2-8%), and the livestock (2-12%) (Miner, 1995).

In open feedlots, weather, animal activity, humidity, and surface moisture influence odor production and dispersal. Inadequate drainage of feedlots is a potential source of odor (Sweeten and Rodriguez-Akabani, 1994). Standing water will promote anaerobic conditions and associated odors. Dust can also be a problem for open feedlot operations. Dust from surfaces, alleys, and roads is affected by feedlot area, animal density in pens, wind speed, precipitation, and evaporation patterns (Sweeten, 1991).

Manure/waste water storage and treatment

Waste water lagoons are effective for both long-term storage and treatment. Lagoons usually have a large surface area. This implies a significant potential for odor release if the lagoon is not functioning properly (Fulhage, 1996b). The startup phase of an anaerobic lagoon, which can last for a year or more, will produce increased levels of odors until materials and biological processes stabilize. Odor problems associated with established lagoons are slug loading (rapid addition of raw wastes), inadequate dilution with water, inadequate volumes for treatment, and seasonal thermal inversions.

Common structures for temporary waste water storage are: below-slat concrete tanks; open concrete tanks outside the building; covered concrete tanks; above-ground concrete or metal tanks; and earthen storage basins. Swine waste stored in these structures is generally concentrated (NPPC, 1996) and anaerobic (Fulhage, 1996b; Swine Odor Task Force, 1995), both of which contribute to odor potential. However, the surface area available for odor release from temporary holding structures is relatively small (Fulhage, 1996b). Overloading temporary holding structures for surface runoff increases their odor potential (NPPC, 1996). Solid manure can be stored in roofed or unroofed, walled structures (Veenhuizen, 1996). Odors from solid manure storage are considered somewhat minor and inoffensive, due primarily to aerobic bacterial activity (Fulhage, 1996b).

Land application

The main methods of land applying swine waste are: surface spreading (including flood irrigation, sprinkler systems, dry manure spreading, and splash-plate spreading of slurries and liquids), soil incorporation (tilling), and sub-soil injection (NPPC, 1996). Each method has a different potential for generating odors but all can be significant sources of odor if not properly managed.

Surface spreading of untreated liquid swine waste has the highest potential for generating odors because volatile compounds are spread over a large surface area. The National Pork Producers Council (1995) discourages the irrigation of untreated, concentrated, anaerobic liquid manure from temporary manure storage units due to the significant odor potential. Tilling liquid manure into cropland immediately after surface spreading reduces odors. Soil injection has the lowest odor potential of any application method (NPPC, 1996). Tilling and injection are reported to reduce odor release by 90 percent (Switzky, 1992). Surface spreading using high trajectory/high pressure sprinkler systems aerosolizes waste water and increases odors and dispersal distances. The release of odors from surface spreading usually subsides in one to three days, unless the weather is particularly warm and humid (Veenhuizen, 1996).

Pumping systems used to draw liquid manure from lagoons and temporary storage units for land application can increase release of odors if not built correctly. Pumping activities can excessively agitate manure liquids, promoting odor dispersal. Pumps not completely submerged in storage and treatment facilities can result in release of five times the odor of submerged pumps (NPPC, 1996).

3. IMPACTS OF SWINE ODOR

Numerous articles have been obtained by or provided to EPA which indicate that pig farm odors may have nuisance and health impacts. These odor impacts are not consistently predictable due to constantly changing weather. Odors can carry for several miles, depending on sources and weather conditions. Odors have been noticed as far away as four miles from swine facilities on a windy day (Wood, 1994). To further complicate matters, odors affect people differently. Individual reactions to odors are influenced by personal preferences, opinions, experiences, and the varying sensitivities of olfactory systems (Mackie, 1994).

The table below characterizes some gases produced by decomposing manure and lists some of their possible effects; more extreme effects would not be likely except in the immediate vicinity of (e.g., within) a malfunctioning CAFO.

Character of gases produced by decomposing manure

(adapted from Taiganides and White, 1969).

Gas	Odor	Characteristics	Physiological effects
Ammonia (NH_3)	Sharp, Pungent	Lighter than air; results from anaerobic and aerobic activity; soluble in water	Irritation to throat and eyes at 400 and 700 ppm, respectively.
Carbon Dioxide (CO_2)	Odorless	Heavier than air; highly water soluble; results from anaerobic and aerobic activity	Increased breathing, drowsiness, headache at 20,000 to 40,000 ppm
Hydrogen Sulfide (H_2S)	Rotten egg smell	Heavier than air; low odor threshold; soluble in water	Irritation of eyes and nose; headache, dizziness; nausea, insomnia at 100 to 500 ppm
Methane (CH_4)	Odorless	Much lighter than air; not very soluble in water; product of anaerobic activity	Headache at 500,000 ppm

The Swine Odor Task Force (1995) groups impacts in two categories: health and welfare, and community impacts.

Health and welfare impacts

Malodor is often considered an indicator of a possible health risk. Agricultural odors can cause nausea, vomiting, headaches, produce breathing difficulties, upset sleep, cause stomach upsets, loss of appetite, and irritate eyes, nose, and throat; asthmatics, persons with allergies, and others with preexisting respiratory and cardiovascular diseases reportedly are particularly susceptible to the effects of unpleasant odors (Watts, 1992).

Taiganaides and White (1969) reported that human responses to noxious odors are similar to animal responses, though varying in intensity with weight and time of exposure. Young animals are more susceptible to the effects of inhaled noxious gases than older animals; on the other hand, effects on eyes or other external parts of the body may be expected to be the same for both large and small animals. Chronic exposure to sublethal concentrations of noxious gases can have serious effects on animal health. Taiganaides and White reported that swine exposed continuously to relatively low levels of hydrogen sulfide (about 20 parts per million) develop photophobia (fear of light), anorexia and nervousness; physical symptoms appear at higher levels.

Schiffman (1994) reports that people living near intensive swine operations with nuisance odor problems experience increased levels of tension, depression, anger, fatigue, and confusion compared to average persons of the same gender, race, age, and years of education not located near swine facilities. Schiffman also reported that the body releases adrenaline when irritants come into contact with the nose.

Possible reasons for adverse impacts from odors are: 1) the unpleasantness of the sensory quality of the odor; 2) the intermittent nature of the stimulus; 3) learned aversions to the odor; 4) direct physical effects from molecules in the plume, including nasal and respiratory irritation; 5) possible chemosensory disorders; and 6) unpleasant thoughts associated with the odor (Schiffman, 1994). These findings are consistent with similar studies of nuisance odors in the environment (Swine Odor Task Force, 1995).

A pilot study of odor impacts downwind of different sized swine facilities was undertaken by personnel at the University of Iowa (abstract, Stookesberry, et al., 1996; report as yet unpublished). The study examined possible toxic responses associated with three categories of odorants: ammonia, particulates and endotoxins (toxins from destroyed cells of certain bacteria). Measurements were taken 30 meters downwind of swine facilities. Outside concentrations of dust and endotoxin were mostly below detectable limits, and thus below occupational health guidelines for acute toxicity. Measurable concentrations of ammonia were always higher downwind than upwind, but were still below acute toxicity guidelines. The study concluded that subacute symptoms experienced by rural residents, especially by sensitive individuals, may be related to detected quantities of ammonia. "Further research to investigate relationships between exposures and symptoms needs to be performed to determine possible associations".

Community impacts

Individuals living in communities with swine odor problems are concerned about declines in property values, comfort, health and welfare, aesthetic amenities, and other quality-of-life issues (Swine Odor Task Force, 1995). Some neighbors of swine CAFOs subjected to nuisance odors feel that the odors are not easily incorporated into patterns of daily living, including eating and sleeping (Schiffman, 1994); i.e. nuisance odors may interfere with the normal use and enjoyment of property.

It is possible that CAFOs with odor problems could discourage other kinds of economic development nearby, especially those projects sensitive to odor and aesthetics, such as retirement communities, tourism and recreation businesses. There are fears that certain types of industries may not locate in a community if they feel their employees will have to live or work in areas that are smelly or unhealthful (Swine Odor Task Force, 1995).

4. MEASUREMENT

An obstacle to evaluating odors and their impacts is that the constituents and sources of odors are not easily identified nor quantified, though techniques are improving. Most available information is either anecdotal or from studies that did not involve standardized odor measurement techniques and/or were unreplicated. And, odors from all sources do not simply add in intensity when mixed, but a complex process involving addition, mixing, and masking takes place. Mixtures of odorants can be additive, subtractive, synergistic, or counteractive as compared to intensities of the individual compounds (Barth et al., 1984; Smith, 1995).

Measurement approaches

Measurable characteristics. As perceived by humans, odors have five quantifiable properties (Sweeten, 1995a; Sweeten, 1988):

1. intensity, concentration, or strength;
2. character, degree of offensiveness, or hedonic tone;
3. perceived offensiveness;
4. odor frequency;
5. duration.

The first two factors can be measured using odorant monitoring or sensory measurement methods as described below. Perceived offensiveness is a qualitative response of humans to both the character and intensity of an odor. Odor frequency and duration are partly dictated by climatic conditions, including wind direction frequency, atmospheric stability, and moisture conditions; the climatic variables are uncontrollable except by initial site selection (Sweeten, 1995a; Sweeten, 1988).

Measurement techniques. Odor can be measured as the actual physical intensity of odor-causing chemical compounds, or as the perceived sensory level of their offensiveness as rated by a subjective recipient of the odor (TIAER, 1994). This implies two approaches to odor measurement: 1) odorant monitoring (i.e., instrumental measurement of specific known odorous gases); and 2) sensory measurement (i.e., using human odor panelists).

Measurement of odorous gases. Sweeten (1995a) summarizes research on a number of techniques for measurement of specific odorous gases such as ammonia, including gas chromatography (differential adsorption), mass spectrometry (light spectrum differentiation), packed bed chemical-specific syringe tubes, ammonia absorption traps, and electronic sensors. These techniques have some history of being used to measure livestock odors, and can provide concentrations of specific odorous gases relative to their threshold limit value (TLV) in parts per million (ppm) and odor threshold in ppm.

Electronic sensors for detection of volatile gas are experimental, but have the potential for linkage to remote, automated odor monitoring networks. Electronic sensor methods include thin-film metal oxide semi-conductor capacitors; chemically modified field-effect transistors; optical devices; and piezoelectronic quartz crystal devices (Mackay-Sim, 1992). With the latter, antibodies or receptor proteins from the human sensory cells attached to the crystal surface are being used in research instrumentation to imitate the human olfactory system. Some instruments are mobile, hand-held devices; some require laboratory analysis and/or have difficulty with complex feedlot odors. Preliminary results from electronic sensors appear promising, though further development is needed prior to common usage (TIAER, 1994).

Monitoring specific odorous gases known to be emitted from livestock feeding facilities has proven useful in identifying approaches to abate the release of the specific gas monitored. However, research has often been inconclusive in establishing a linkage between the selected odorant and human-scale odor concerns, including humanly-perceived odor intensity and offensiveness.

Measurement of sensory impacts. Olfactometers are the most common method for measuring sensory odor impact. Olfactometers allow quantification of odor strength by human panelists in terms of perceived odor intensity. Olfactometers usually involve a panelist wearing a hood or mask through which gases can be passed at controlled volumes. Gases for sampling can be collected, stored and taken to the panelists or the gases can be sampled on-site.

Olfactometers either use suprathreshold referencing or dilution to threshold to obtain odor measurements (Sweeten, 1995a). Suprathreshold referencing consists of comparing the perceived intensity of undiluted ambient odors with the intensity of known concentrations of 1-butanol (1-butyl alcohol) in air. Dilution to threshold is where odorous samples and non-odorous (dilution) air are mixed to various levels of dilution and presented to panelists at a controlled flow rate; panelists determine when the odor is reduced to a detection threshold. The volumes of odor free air needed to reach the detection threshold are referred to as dilutions to threshold (DT) (McFarland and Sweeten, 1993), below which the odor of a substance will not be detectable under any practical circumstances, and above which individuals with a normal sense of smell (e.g., 50% of the panelists) would readily detect the presence of the substance.

Most olfactometers can provide internally consistent results, and a sizable body of data has been developed around certain olfactometers. For example, the Scentometer, a dilution to threshold device, is a rectangular, clear plastic box containing two chambers of activated carbon (for dilution) with air inlets over each carbon bed, two nasal ports, and four odorous air inlets of various sizes allowing different dilutions. The Scentometer is simple, portable, and can provide results rapidly in the field (e.g., Sweeten and Miner, 1993; McFarland and Sweeten, 1993).

Additional control over odor measurements (e.g., better accuracy, reproducibility and statistical reliability) can be provided by equipping olfactometers with the capabilities of "dynamic sampling" and "forced choice" (Sweeten, 1995a). Dynamic sampling involves tubing and a mixing chamber or manifold in which ambient, odorous air is mixed at controlled amounts with "non-odorous" air (e.g., compressed bottled breathing air or charcoal-filtered air). Forced choice refers to devices with two or more sniffing ports (a standard triangle design provides for a "double blind"; see ASTM, 1991). One port contains the diluted odor sample, while the other(s) contain "non-odorous" air. The port with odor is changed at random. Panelists are required either to identify (or guess) which port contains odor, hence the term "forced choice".

Results from one olfactometer to the next may not be comparable due to the various designs. However, olfactometry using human sense of smell as the sensor is the most valid method for ambient odor measurement (Berglund et al., 1988), and for relating the odor levels to the experience of affected human receptors. Several U.S. states and local entities have adopted property line standards for odor intensity based on field measurements of dilutions to threshold (or "odor units") (Sweeten, 1992a), though none have been developed specifically for swine odors. Sweeten (1995a) urges that, as an alternative to the prospect of regulatory enforcement and litigation, research utilizing the most refined and standardized methodology available be funded, established and completed with results interpreted and placed in common practice in terms of design and management of CAFOs.

Measurement findings

The Swine Odor Task Force (1995) reported that in North Carolina, despite some limitations, two measuring instruments generally agreed on the ranking of odors at six swine facilities. One of the instruments was a Scentometer, measuring human reactions to smell, and the other was an Odor Monitor (TM), measuring odor-causing molecules. In the south central U.S., much research using the Scentometer or other techniques has been at open cattle feedlots, and may not be applicable to housed swine operations.

Some findings of interest regarding measurement of odors are listed below.

- Lindvall, Noren and Thyselius (1974) used sensory methods (a controlled dynamic system of dilution using exposure hoods) to measure swine and cattle odors from manure and urine of several types (aerated, treated with ammonium persulphate, untreated) using different types of tillage and spreading equipment during different times of year. Their findings included the following:

    - untreated and continuously aerated swine manure showed relatively high odor strength values;
    - swine manure treated with ammonium persulphate presented a considerably weaker odor;
    - surface spreading with swine manure caused relatively high odor values;
    - injection of swine manure reduced odors by about two powers of ten, to that of unmanured soil;
    - the difference between cattle and swine manure was more than one power of ten;
    - untreated swine manure is relatively less easy to dilute.

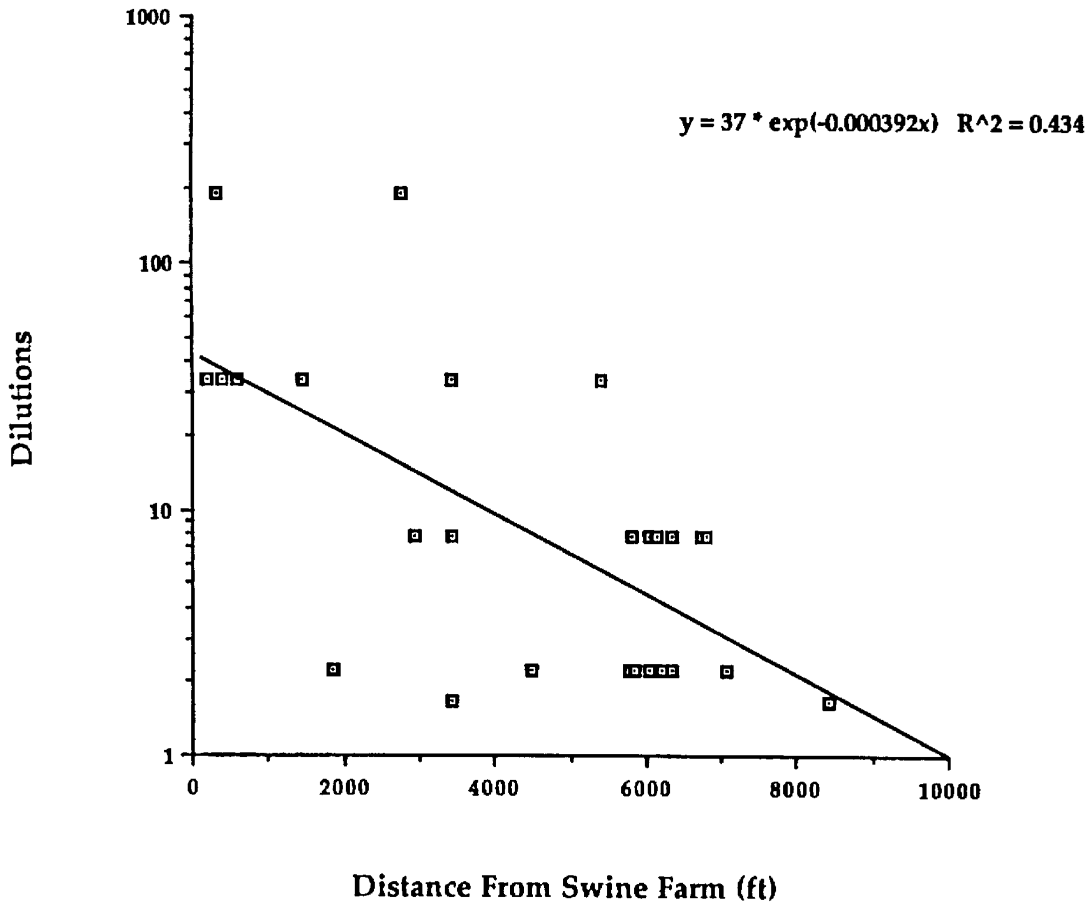
- Miner and Stroh (1976) found that odor detection capabilities of the Scentometer were limited and could not provide intermediate data points within the range of 31 to 170 dilutions to threshold (DT) as were needed to successfully correlate odor with ammonia.

- Tucker (1992) found that odor concentration peaked near mid-day, with least odor in early morning, over the day-time hours studied.

- Schiffman (1994) found that most complaints from swine odors occur early in the morning or late at night when there is laminar rather than turbulent airflow.

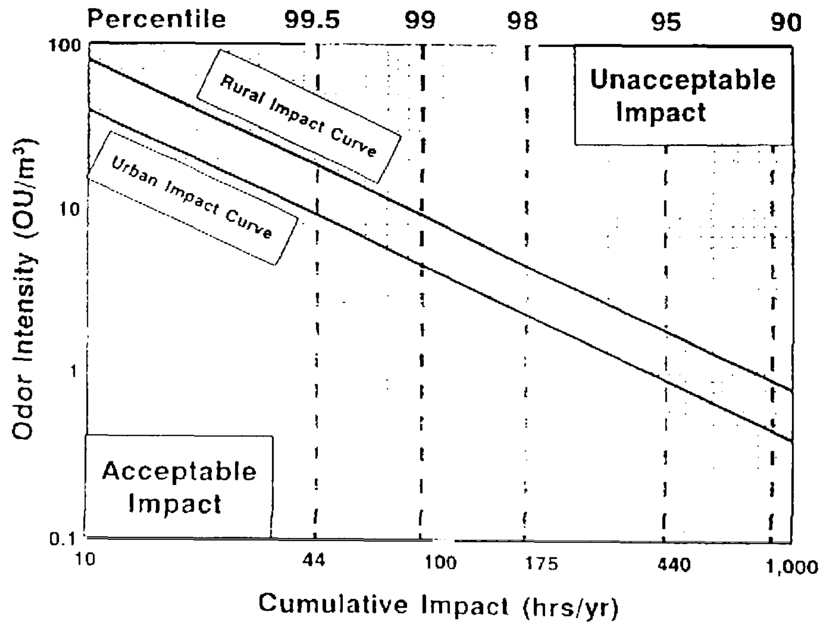
- Several authors confirmed that odor increases with wetness and heat.

- Sweeten (1992) used a Barnebey-Cheney Scentometer to measure odors at two swine farms, in Nebraska and Arkansas, involved in litigation resulting from odors. Principal odor sources, in order of importance, were: dead hog pick-up site, primary lagoon, finishing and nursery buildings, and center pivots. The farrowing house and gestation barns presented little odor problem. The center pivots produced relatively lower odor intensities but represented relatively large line sources of odor that were closer to neighbors in most instances. For the Nebraska farm (an 8,400 sow farrow to finish operation with a one-time capacity of 72,000 hogs on a 160 acre tract surrounded by irrigated farmland), odor observations were plotted as a function of distance downwind (see below). There was a marked reduction in intensity within the first half-mile followed by a more gradual reduction thereafter. At the Arkansas farm there appeared to be little or no relationship between odor intensity and strength versus ammonia or hydrogen sulfide concentrations.



Reduction of odor intensity (dilutions to threshold) with distance from swine Farm 1, Nebraska.

Watts and Sweeten (1994) proposed that the first step in a uniform regulatory approach to odor nuisance is the standardization of odor intensity measurement, using forced-choice, dilution-to-threshold, dynamic olfactometry, the method used most in Europe and Australia. Panelists would be tested with a reference odorant such as butanol. Assuming a standard method of measurement, odor intensity (impact from a particular enterprise) could be compared to acceptable levels of surveyed community annoyance relative to cumulative annual exposure (frequency times duration) as indicated in the figure below; this model has not been validated. One could then measure odor at the source and model impacts using calibrated dispersion models and local meteorological data. As the figure below indicates, in essence, the public would be expected to tolerate a low odor intensity for a long period of time and a high odor intensity for a short time, but the public would not be expected to tolerate a strong odor for a long period of time.



Proposed regulatory definition of odour nuisance.

(Odour intensity is the modelled intensity averaged over an agreed minute period such as one hour).

Modeling of odor

It is imperative for accurate modeling that the mass emission rate of odor is known. However, in nearly all cases, an analog, dimensionless odor units, has been substituted for mass emission rate. Smith and Kelly (1994) compared two methods for estimating odor emission rates. The first utilized a wind tunnel sampling system to give point estimates of the emission rate. The second used odor measurements downwind of the source to give a spatial average emission rate through a process of back calculation. Both methods are similar in approach but differ in scale.

The wind tunnel method samples emission rate from a small area of source and gives the emission rate corresponding to the average or bulk wind speed in the tunnel. The back calculation method samples 'average' emission rate from a relatively large area of source and gives the actual emission rate for prevailing ambient conditions. Smith and Kelly recommended use of the wind tunnel method in three situations: whenever a point measurement is required; in comparative trials to assess the effect on emissions of individual variables such as feedlot pad temperature or moisture content; and to assess the spatial variability of emissions. In all other instances an estimate by back-calculation would be preferred.

Smith and Kelly noted the difficulty of using odor data in a comparative manner. Because odor concentration measurements rely on the determination of human response thresholds, albeit in a scientific way to minimize known variability and bias, the standard deviation around the mean on each measurement is necessarily relatively wide. Hence validation or comparison of different methods for estimating emission rates would more reliably be done by supplementing sensory odor measurement with a readily measurable odorant such as indols or phenols. Generally speaking, any modeling exercise should be subject to actual field odor measurement to verify the accuracy of results of model output.

McFarland and Merryman (1994) used the Industrial Source Complex Short Term model version 2 (a Gaussian or plume model) to model odor dispersion from dairies. The authors' model attempted to duplicate on-site meteorological and olfactory measurements; it was hoped the model could prove useful in siting CAFOs, in estimating needed buffer distances, and in identifying odor sources. The model did a fairly good job of representing general odor dispersion patterns (see figure below) but was unable to consistently match odor concentrations at receptor points with field data, particularly under highly variable wind. It overpredicted the distance required to reduce odor to a given level. Needed calibration work was outlined but has not been undertaken.

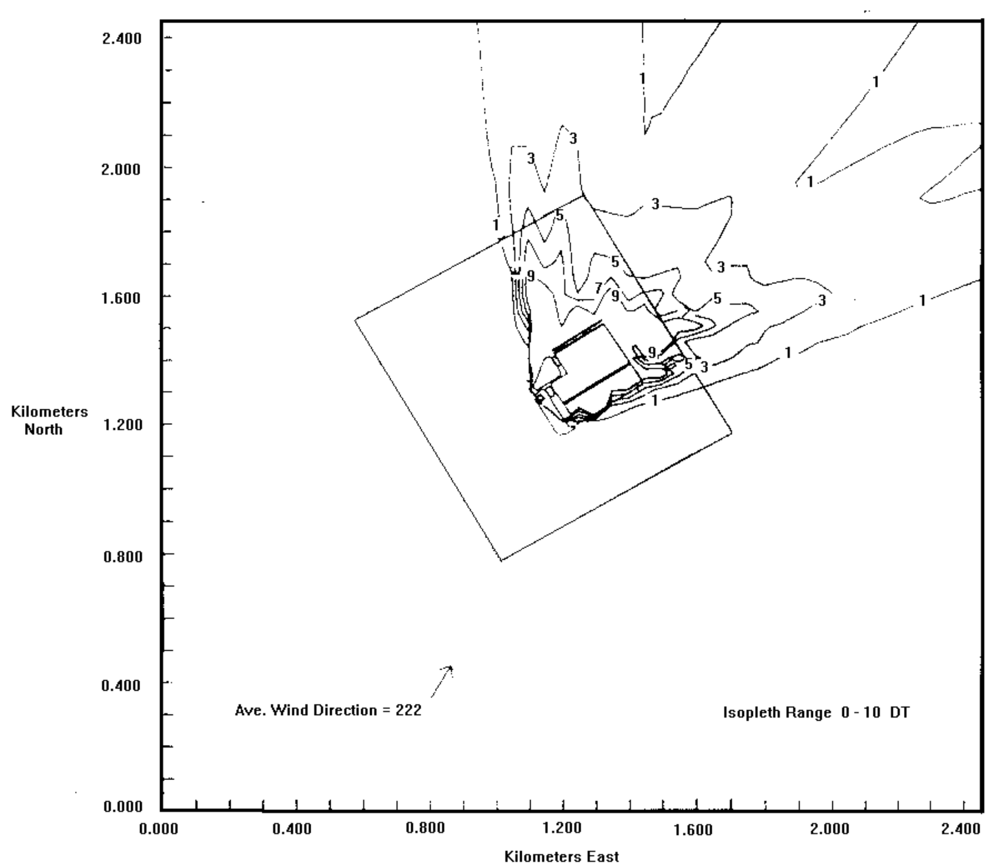


Diagram of the concentration isopleths ranging from 0 to 10 DT produced as output from the ISCST2 model representing weather conditions on Dairy B on August 5, 1993 from 1345 to 1650 (McFarland and Merryman, 1994).

Smith (1995), in evaluating swine odors and licensing of feedlots in Australia, noted that swine odor emissions rates can be related to: feedlot pad moisture content and time since wetting; temperature; and ration (feed). Smith evaluated the usefulness of AUSPLUME, an empirical model which gives instantaneous emission rate as a function of temperature, feedlot pad moisture content and manure depth. Additional research was identified, including a better understanding of climatic (e.g., vertical dispersion) and terrain effects (e.g., roughness). For example, experiments are required to accurately determine the full effect that wind speed and the shape of the wind speed profile have on the rate of odor emissions. Smith provided other examples, along with the current status of research in each case.

The table below provides a list of matters to be resolved regarding use of AUSPLUME prior to successful licensing of Australian feedlots in terms of acceptable odor emissions. Smith noted that while AUSPLUME would likely overestimate downwind concentrations, it should be viewed mainly in a relative sense, according to the interpretation one wishes to place on the result of the modeling.

> "The results from the dispersion model should not be seen as an absolute prediction of an odor concentration at the receptor but simply as a number predicted by an accepted model (used in a standard manner) which can be compared to a limit predetermined by the regulatory authorities. Feedlots can be sited so as not to exceed this limit. Establishment of the limit would involve a similar modeling process performed in conjunction with an odor nuisance survey" (Smith, 1995).

Precursors to an odor licensing system in Australia (Smith, 1995)

1. The dispersion model.	AUSPLUME is the present industry standard and there is no reason to change. The puff models currently being developed offer no advantages to the feedlot industry.
2. The definition of an odor unit (OU).	This includes the method of measurement and standardization. Until an acceptable Australian standard is produced the DPI procedure should be adopted, that is, forced-choice dynamic-dilution olfactometry, the result standardized to a panel with a butanol detection threshold of 50 ppb.
3. Estimation of the source emission rate	Acceptable procedures might include certain wind tunnel sampling, back-calculation, and the predictive model of Lunney and Smith (1995).
4. Standard parameter values in the dispersion model.	Agreed values for the aerodynamic roughness for various surfaces; averaging time; and method for estimating the dispersion coefficients.
5. Terrain	Procedures for dealing with complex terrain.
6. Wind data	Historical records of wind speed and direction are available only for a limited number of sites in Australia. A consistent procedure is required for generating data for sites for which records are not available.
7. What constitutes an acceptable outcome	The outcome of the modeling will be presented in terms of the concentration, frequency and duration of odor events. Regulators will need to specify and obtain industry agreement for acceptable values for these outcomes.

Jiang (1996) reported that for several Australian waste water treatment plants, odor samples are collected from liquid and solid surfaces using a portable wind tunnel system, and then tested using a dynamic olfactometer. Odor emission rate information is then keyed into a dispersion model that predicts odor impacts on the local environment, and provides information for surveying the community, reducing odor, and monitoring control equipment.

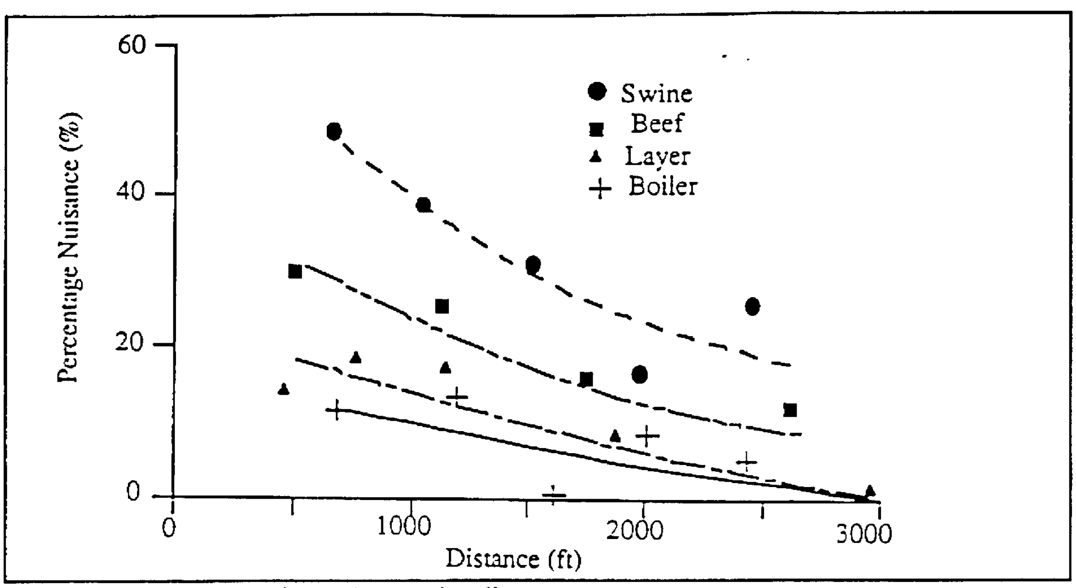
5. MANAGEMENT PRACTICES

The degree of impacts from odors generated by CAFOs depends primarily on site selection and on how successful waste management practices prove to be (Swine Odor Task Force, 1995). Odor nuisances can be reduced through: 1) thoughtful site selection; 2) good housekeeping of open feedlots and housing facilities; 3) design and management of manure/waste water storage and treatment systems, and 4) proper land application equipment and timing (Veenhuizen, 1996). This section provides examples of these aspects of CAFO management and summarizes them in table format following each heading. Additional insights are provided in the index.

Site selection

It is important to site swine facilities to minimize the impact of odor on neighboring residences. Pork producers should have as a goal to design, construct, and manage their operation to minimize odors experienced by neighbors. Important considerations that will be helpful in locating swine operations are: distance from neighbors; size and orientation of building, storage, and treatment facilities; prevailing winds and topography.

While odor nuisance potential decreases exponentially with distance (Van Kleeck and Bulley, 1994), long distances are necessary if no odor at all is to be detectable. The American Society of Agricultural Engineers (ASAE, 1994) indicates that a desirable distance from neighbors for siting livestock facilities in general is one mile from housing developments and 1/4 to 1/2 mile from neighboring residences. Veenhuizen (1996) presented survey results that indicate swine odors are perceived as nuisance odors at a greater distance than other livestock odors (see graph below).



Nuisance perception and separation distance.

The graph indicates that at roughly one-half mile, the potential for nuisance complaints from swine facilities is still 25%, or about twice that of beef facilities (Van Kleeck and Bulley, 1994). Similarly, Lindvall et al. (1974) found that the difference between cattle and swine manure was more than one power of ten. Thus a preferable distance from swine CAFOs to housing developments could be 2 miles instead of one, and, as Veenhuizen (1996) notes that odors from large swine units are often noticeable up to 3 miles away, a 4 mile separation distance could be preferable (though not always feasible) for larger swine CAFOs. The potential for complaints is likely to be cumulative and increase where swine CAFOs are located within a few miles of each other, and where residences are between or downwind of multiple CAFOs. Smaller CAFOs, and those managed for odor reduction, and might not draw complaints at lesser separation distances.

Prevailing winds should be considered in site selection to minimize the frequency of odor transport to housing developments or neighboring residences. Siting CAFOs downwind of the majority of neighbors, relative to prevailing winds, will decrease odor transport to neighbors (Miner, 1995). Prevailing winds are especially important where they are fairly constant and predictable, as on the Great Plains. As discussed in the previous section, Watts and Sweeten (1994) proposed a conceptual model relating acceptable odor concentration to annual exposure (frequency times duration); this model has not been validated.

The orientation of building, storage, and treatment facilities affect odor transport. Odor is carried downwind and is typically diluted in a vertical direction, with relatively less dispersion by fanning out in the horizontal direction. The result is that the area affected by odors downwind is essentially no wider than the odor source. By orienting odor sources to minimize exposure to the wind (i.e. orienting the maximum length of the facility in the same direction as the dominant wind), less odor impact is likely to be experienced downwind by neighbors (Miner, 1995).

Topography, vegetative wind breaks, and unique meteorological conditions affect odor transport. Both sloping landscapes and air inversions can affect air drainage, causing odors to move downslope in calm conditions. Trees and natural barriers tend to lift and mix the air (ASAE, 1993), promoting dispersion and dilution of odors. Vegetative barriers planted around confinement buildings, open lots, lagoons, and/or land application areas may thereby help reduce odors. Veenhuizen (1996) recommends windbreaks of two to three rows of trees to reduce aerosol drift. Few if any studies directly address the total impact of vegetative barriers; however, many people give testimonials to their benefit (Miner, 1995).

SITE SELECTION MANAGEMENT FACTORS:	DESIRABLE CRITERIA:
Distance from residences	At least 2 miles and preferably 4 miles for larger facilities
Distance from other CAFOs	Several miles, to reduce the potential for cumulative impacts
Lagoon location	Lagoons should be close to the animal housing facility and as far from neighbors as practicable; all else being equal, larger lagoons, and lagoons with relatively high volatile solids loading rates, should be farther from neighbors
Location relative to climatic data	Downwind from closest neighbors relative to wind direction frequencies
Orientation of CAFO facilities	Oriented to minimize exposure to prevailing winds
Vegetative barriers	Used between neighbors and potential odor causing

	facilities, such as animal housing, storage/treatment, and land application sites

Animal Housing

Open swine lots. For open lots, manure treatment for odor control consists of maximizing aerobic conditions. For instance, primary odor control approaches for feedlots are: 1) to keep feedlot surfaces and manure dry, and 2) to maintain a minimum inventory of manure on the lot (Sweeten, 1990). Lots should have sufficient drainage to minimize puddling and wet surfaces (NPPC, 1996). Prompt collection of water and solids from runoff and manure handling will minimize the amount of manure anaerobically decomposing on a lot. Lots can be organized to promote dunging for easy manure collection by placing watering troughs away from areas of heavy activity (i.e. eating and sleeping areas) (NPPC, 1996). Good sun angles for drying, and prompt dead animal disposal, are both important for reducing odors.

Buildings. Good housekeeping is a key to odor abatement in confinement buildings. Good housekeeping relies on easily cleaned interior surfaces, maintaining building cleanliness, careful feed and animal handling, and good ventilation. Odors from anaerobic decomposition of manure will be reduced by keeping surfaces dry and clean of manure. Buildings should be designed and operated so as to prevent dirty, manure covered swine. For example, slotted floors can be easily flushed; emissions from slotted floors are low compared to other surfaces such as solid concrete (Miner, 1995).

The only waste management technique which can reliably reduce livestock building odor emission is prompt, frequent removal of waste from the buildings. The National Pork Producers Council believes daily flushing systems generate less odors than any other manure handling system for confinement buildings; flushing several times a day is recommended (NPPC, 1996; Safley, et al., 1993).

Swine building ventilation air can be treated or oriented to reduce ammonia and odor impacts. Soil filters with perforated pipe in a shallow soil bed have proved effective for scrubbing odors from swine building exhaust air and other odorous sources (Sweeten et al., 1991; Miner, 1995). Building vents and fans can be directed away from sensitive receptors, and exhaust fans oriented upwards to aid in dispersion.

Dead animal disposal and storage. Common methods of carcass disposal used are rendering, burial, incineration, and composting (Miner, 1995). Composting dead swine is very cost effective, simple, and has no negative environmental impacts (Fulhage, 1994). Refrigeration is sometimes used for storage of dead animals until they are picked up for disposal (Miner, 1995).

ANIMAL HOUSING MANAGEMENT FACTORS:	DESIRABLE CRITERIA:
Open feedlots	
Organization	Dunging promoted in easily cleaned areas; sun angle favorable for drying (e.g., feed, water sites); adequate spacing per head; shades oriented north-south and/or slotted
Drainage	Feedlot surface, alleys, ditches graded to shed water rapidly; slopes of 2% or more away from feeding areas; concrete pads extending at least 8 feet away from feeding areas and watering facilities
Lot cleanliness	Manure and water frequently collected from feedlot surfaces

	and runoff collection systems; spilled feed and manure removed from beneath fence lines and feeders

ANIMAL HOUSING MANAGEMENT FACTORS:	DESIRABLE CRITERIA:
Confinement buildings	
Building interior	Smooth surfaces with a minimum of cracks, crevices
Building cleanliness, dust control	Regular removal of settled dust and manure from surfaces (e.g., floors, walls, fans); bedding replaced frequently; odor potential minimized in feed delivery (e.g., enclosed system; no old food around feeding area)
Ventilation	Under floor manure storage vented; intakes positioned away from dust sources and manure pits
Manure management	Frequent removal, using fresh or well-treated water; flushing systems flushed as frequently as necessary each day for odor control; pit recharge systems partially drained, refilled at least weekly
Exhaust release, orientation, treatment	Alternatives include: elevated source release (stacks); exhaust air directed up or away from neighbors; air treatment (conventional air scrubbers, biofilters and bioscrubbers; or thermal incineration/catalytic oxidation)
Both	
Dead animal disposal and storage	Prompt rendering, burial, incineration, or composting; refrigerate if not disposed of before decomposition begins
Animal cleanliness	Animals clean of manure to extent practical

Manure/waste water storage and treatment

Storage. Manure storage facilities can usually be categorized as solid, slurry, or liquid, depending upon how the manure is handled. Solid manure usually has a solids content greater than 20-30 percent, and will not flow. Odors from solid manure storage is considered somewhat minor and relatively inoffensive, due primarily to aerobic bacterial activity. Excessive moisture in solid manure can lead to anaerobic conditions which give rise to offensive odors.

Slurry has a solids content in the 5-15 percent range, and it generally will flow if properly agitated and mixed. The anaerobic nature of decomposition of slurry manure can cause offensive odors and release of hazardous hydrogen sulfide gas during agitation and subsequent land application (Fulhage, 1996). Common slurry manure storage structures are: below-slat concrete tanks, open concrete tanks outside the building, covered concrete tanks, above-ground concrete or metal tanks, and earthen storage basins (Veenhuizen, 1996; NPPC, 1996). Temporarily stored manure slurry may be land applied or, commonly, flushed regularly into a waste water lagoon.

Liquid manure is less than 5 percent solids and usually can be handled with conventional pumping equipment (Fulhage, 1996b). Liquid manure is commonly stored and treated in waste water lagoons.

Temporary storage structures should be covered; a concrete lid, a floating crest, or a floating membrane can reduce odor release until the storage is agitated and emptied. Placing the agitation pump to discharge below the water surface and maintain any crust will reduce the release of hydrogen sulfide related odors (Veenhuizen, 1996). Lagoon covers may reduce odor emissions; options include rigid or flexible plastic membranes and floating organic mats. Such covers may be expensive, and while effective, they may be subject to photodegradation and wind damage over time; floating organic matter covers may be effective seasonally (Sweeten, 1991). It is important to provide adequate storage capacity in order to allow flexibility in land application scheduling to avoid high risk odor conditions.

Anaerobic lagoons. The most common type of waste water treatment system used which also combines storage is the anaerobic lagoon. Design and management are key factors in maintaining acceptable odor levels from lagoons (Fulhage, 1996b). Both one and two stage lagoon systems are used; the latter includes a primary lagoon mostly for treatment and a secondary lagoon for storage and waste water "polishing". Low odor intensity should be detectable from properly designed and managed anaerobic lagoons in southern states except during a short warm-up period in the spring.

Odor tends to be proportional to lagoon loading rates (Swine Odor Task Force, 1995); lagoon loading rate refers to the mass of volatile solids per unit of lagoon liquid volume reserved for treatment, in pounds per cubic foot (ASAE, 1994). The American Society of Agricultural Engineers has produced lagoon depth standards (ASAE, 1994). Increasing depths by several feet more than ASAE standards, where water table and geology allow, will result in increased volume and lower loading rates (Safley, 1994a). Monitoring of simulated swine lagoons of various sizes by Overcash et al. (1976) indicated that a discernible odor threshold for anaerobic swine lagoons exists at approximately 0.21 to 0.41 m^3/kg liveweight.

Complete digestion by anaerobic bacteria yields methane and water, which are odorless. Incomplete anaerobic decomposition causes lagoon odors. Complete digestion would result in bacteria die-off, so the digestion process must be on-going. However, especially inadequate decomposition (and greater potential for odors) occurs when retention times are too short, or lagoon loading rates increase due to expanding animal numbers, slug loading, concentrated waste streams, and/or inadequate water for dilution.

Incomplete decomposition of manure can also occur when conditions are not favorable for anaerobic bacteria (cold temperatures, low pH) (Veenhuizen, 1996); under these conditions, odor is more likely, especially if the lagoon is disturbed during windy conditions or during drawdown for land application. Lagoon odors can then combine with odors resulting from land application. Odors resulting from lagoon "turnover" can result from temperature changes in spring and fall; agitating the lagoon can help shorten the turnover period (Veenhuizen, 1996). Refer to the Glossary (Anaerobic ...) for additional information.

Anaerobic digesters. Anaerobic digesters are enclosed tanks with controlled conditions wherein manure is biologically degraded (Miner, 1995). Anaerobic digesters provide an effective means of controlling odors both during and after treatment. Digesters are covered, heated and stirred to shorten the time needed to stabilize the waste, to control odors, and to capture the methane produced. A carefully controlled digester can stabilize manure in 20 to 30 days (Veenhuizen, 1996). Anaerobic digester treatment can reduce digester effluent and land application odors up to 80% (Koelsch, 1995).

Very little odor is produced from a properly managed anaerobic digester (Miner, 1995). Provided adequate retention time and specific temperatures, a well-controlled anaerobic digestion process will degrade the vast majority of compounds that contribute to odors (Vetter, 1994). The resulting sludge is much less odorous than raw manure (Miner, 1995). Farms with odor concerns should plan waste handling facility designs that include space available for the possibility of this alternative (Veenhuizen, 1996).

Aerobic treatment. The main advantages of mechanically aerated lagoons over anaerobic lagoons are odor reduction, high treatment efficiency and relatively small land area requirements (Sweeten, 1980). Aeration systems have been shown to reduce odor emissions up to 75% to 86% and reduce odor intensity and offensiveness (Veenhuizen, 1996). Mechanically aerated lagoons are an alternative in highly populated areas or when there is a limited area available for manure storage, and they can be designed to standard lagoon depths and can meet defined objectives in terms of odor control (Miner, 1995). Oxygenation capacity sufficient to satisfy at least the five-day biochemical oxygen demand (BOD), or the majority or all of the chemical oxygen demand (COD) plus the nitrogenous oxygen demand, is generally required (ASAE, 1994). In aerobic digesters, continuous aerobic culture treatment for the purpose of odor control is affected by treatment time, temperature, dissolved oxygen level, and insulation factors (Miner, 1995).

Facultative lagoons. Facultative lagoons combine anaerobic and aerobic bacterial treatment (Safley, 1993). Mechanical aerators are used to aerate the lagoon surface and can effectively control odors from the lagoons (Miner, 1995). According to some reports, aeration for odor control requires only sufficient oxygen to equal the 5-day BOD of the manure during the six warmer months of the year, though this is not a well proven concept. A continuous loading scheme is recommended for best results.

Composting. Composting can be utilized for solid manure or separated solids, adding bedding or another carbon source such as agricultural residue. The drying and acidifying of waste stops the microbial action that produces odor-causing compounds (Swine Odor Task Force, 1995). Composting can be used to stabilize manure wastes before land application (Veenhuizen, 1996). Composting of solid manure will rapidly stabilize the material and reduce odor in storage and land application, and reduce or eliminate fly breeding potential. Finished compost is a dry material, low in odor, which can be bagged. In addition to sufficient space, time, containers, and mechanical aeration, composting requires odor control strategies due to high levels of ammonia loss (Veenhuizen, 1996). A regional composting facility could be economical for an area with a high concentration of agricultural activities which produce large volumes of manure.

Litter systems partially compost manure in place if moisture control is adequate. The deep litter method, being tested in hog facilities in Europe and Japan, involves raising pigs on a 28 to 32 inch deep bed of organic material (usually sawdust). A bacteria/enzyme compound anaerobically decomposes the bedding and the manure. Manure takes about one month to decompose. The process of turning over the bed eliminates ammonia and releases heat, thus odors inside and outside the building are reduced (Randolph, 1991). The Ishigami System is a variant of the litter system. Facilities using this system in Japan report success in minimizing odors. The floor of a 20x60x15 foot polyethylene tunnel is covered with 10 to 14 inches of sawdust. Swine are fed an enzyme/bacteria/mineral mix which inoculates the sawdust bed through the dung (Gadd, 1991).

WASTE STORAGE AND TREATMENT MANAGEMENT FACTORS:	DESIRABLE CRITERIA:
Storage	
Exposure to atmosphere	Temporary liquid or slurry manure storage covered if inadequate site isolation
Capacity	Adequate to provide disposal flexibility
Pumping	Agitation pumps should discharge below the water surface
Solid manure storage	Minimize moisture (less than 50 %); see Composting,

	Dehydration, and Storage entries in Index
Separated solids	Removed promptly and composted and/or disked or injected into the soil

WASTE STORAGE AND TREATMENT MANAGEMENT FACTORS:	DESIRABLE CRITERIA:
Lagoons	
Capacity	Adequate to allow volatile solids loading rates which minimize odor, and sufficient (e.g., 6 months) to allow effluent removal to coincide with advantageous weather conditions
Start-up	Start in late spring or summer; minimum treatment volume filled with water prior to introducing manure; loading rates gradually increased to design loading rate
Operation	Lagoon not overloaded above design volatile solids loading rate; reduce loading rates in winter if feasible; nearly constant level of suspended solids and dissolved minerals; daily or frequent loading to avoid "shock" loading
Aerobic lagoons	Aerators sized to provide sufficient oxygen to satisfy the five-day BOD and nitrogenous oxygen demand, or the majority of the COD
Effluent removal	Lagoon not pumped below minimum design volume (40-50% of active volume left); pumped from second stage lagoon if available; removal pumps located as far as possible from inflow line and above the designed sludge storage volume; in cooler climates, lagoon liquid only removed during warmer months, no more than 25% of lagoon volume removed in the late fall to maintain sufficient bacteria
Other treatment methods	
Digesters	Operated to maximize rate of organic matter stabilization and odor control (e.g., loading rate, retention time and temperature)
Composting	Ammonia emissions controlled; frequent turning (e.g., weekly) or mechanical forced aeration, and several weeks or months (8-16 weeks) required
Alternative systems	Closely monitored, as methods are experimental, rare, or site specific, requiring careful, justifiable design

Land application

Land application is the primary method of waste water and solid waste disposal and is an integral part of nearly every manure handling system (ASAE, 1994). Techniques include sprinklers, dry manure spreading, tank wagons, and level border flood irrigation systems. *Studies indicate that land application is the basis for a majority of odor nuisance complaints from swine operations* (Miner, 1995).

Timing. Odors are most likely to be noticeable nearest to land application sites during and shortly after application of undiluted waste water (Swine Odor Task Force, 1995). Odor impacts may be reduced through timing of the application. The National Pork Producers Council (NPPC, 1996) suggests applying during cool temperatures, mornings and early afternoons to promote vertical mixing of odors with rising air. Dry, clear, windy days are considered the best atmospheric conditions during which to apply with the least resulting odor. Existing and forecasted wind direction should always be considered; applying when wind is blowing away from neighbors will decrease their exposure. It is important to avoid applying waste water when people are likely to be engaged in outdoor activities, i.e., on weekends/holidays (Miner, 1995).

Application. Low pressure irrigation and sprinkler systems are less odorous than high pressure systems because of less drift downwind. The low pressure (e.g., 15 to 20 psi versus 80-90 psi for high pressure systems) reduces ammonia stripping and associated odors. Avoiding extra-fine spray sprinkler heads, which strip ammonia, will limit production of odorous mists that can drift downwind, though this may conflict with the goal of denitrifying to reduce the potential for ground water degradation. Also, dispersal of odors can be reduced by using overhead sprinklers that direct waste water downward towards the ground rather than into the air and winds, as with high trajectory/high pressure systems.

It may be possible to reduce odors by diluting waste water with fresh water prior to application (Kreis, 1994). The ability to do this requires sufficient land and/or moisture balance (common in moisture deficit regions) to accommodate needed nitrogen uptake and hydraulic loading. Use of untreated slurry from storage pits for any type of` irrigation can be very odorous and should be avoided or carefully managed.

Forced injection of waste water or swine manure into the soil has been found to be the most effective method of odor reduction (Lindvall, Noren and Thyselius, 1974). Miner (1995) reported that best results are achieved when the injection unit is either trailed or mounted directly behind the tractor to give immediate injection. Odor intensity from surface application at 400 meters downwind is often perceived to be equal to that from injection at only 50 meters. Injection of slurry can reduce the odor and ammonia emissions by 80% and 95% respectively, compared to conventional splash-plate (tank wagon) surface spreading (Miner, 1995). Soil injection may not be feasible in areas with high water tables in order to protect ground water (Swine Odor Task Force, 1995).

Incorporation, or plowing into the soil of solid, liquid, or slurry manure after spreading, is less effective than injection but is helpful in reducing odors (Miner, 1995). Plowing immediately after application reduces the rate of odor emission during the first hour by 85% and rotary harrowing reduces it by 45%. A reduction of 52% over 4-8 hours was achieved only by immediate plowing. No reduction in total odor emission is detected when incorporation by any means is delayed for 3-6 hours after slurry application. If incorporation of manure is not practical, an alternative is to minimize the number of days spread near neighboring residence, i.e., get geared up to do the work quickly; plan for more storage capacity if necessary to reduce the frequency of spreading manure (Miner, 1995).

LAND APPLICATION MANAGEMENT FACTORS:	DESIRABLE CRITERIA:
Timing	Avoid weekends and holidays; apply solid manure or slurry within four days of excretion;
Location	Minimize land application near residences; make use of vegetative screens
Weather conditions	Utilize winds blowing away from populated areas to dissipate and dilute odors; apply during rising air conditions
Strength of waste water	Dilute with fresh water if possible
Sprinkler system	Low pressure; low trajectory or overhead system; avoid extra-fine spray

Irrigation	Avoid irrigation with untreated slurry: minimize waste water exposure, splashing; plow soon after
Soil injection	Inject immediately behind tractor; avoid high water tables, highly permeable soils
Soil incorporation	Plow or disk immediately (less than 3-6 hours) after application

6. ADDITIVES

Additives discussed here usually are applied: 1) directly to the animals, such as through diet; or 2) to the manure or waste water. These are non-structural actions which can be planned for a new CAFO or taken after a CAFO is operational, to attempt to control odors that persist despite initial design, construction, operation and maintenance efforts.

Diet

Feed additives are intended to improve animal performance and utilization of feed nutrients to reduce the generation of odors (Ritter, 1989). Miner (1995) reports that attempts to control odors through dietary manipulation has involved attempts to:

1. mask the odors;
2. alter the microflora that may produce the odorous compounds;
3. affect enzyme systems that will alter microbial metabolism; and
4. reduce nutrient outputs and/or precursors of odorous compounds.

Miner (1995) provides technical summaries of research in these areas, and is an excellent source for identifying methods and studies which may be of interest. Following are a few examples.

- Experiments are described involving a number of feed additives, including dry and liquid *Lactobacillus acidophilus*, whole milk, yeast, sagebrush, peppermint oil, bentonite and zeolite materials. Results were negative or mixed.

- Current research is described showing that nitrogen output in manure and urine is significantly reduced using phase feeding, split sex feeding and balancing of diet based on ideal protein levels which involves reducing the crude protein of the diet and supplementing with synthetic amino acids.

- Reports are noted showing that imbalances of the C:N ratio in intestinal contents of pigs or anaerobic digestion will produce increased levels of malodorous compounds and reduced efficiencies of nutrient utilization. Increasing the digestibility and retention of nutrients from feeds (increased feed efficiency) will decrease excreted nutrients.

- Numerous studies using various diets are briefly summarized (including those reported in the proceedings of several International Symposia on Digestive Physiology in the Pig). Most of the focus on such studies has been on reducing ammonia emission, with little analyses of other odorous compounds.

- Research is described which manipulates microflora in the pig's digestive system by introducing substrates in the diet or by introducing specific cultures to the digestive system to compete with indigenous populations. Also, microbial groups have been identified based upon their capability to produce or utilize different malodorous compounds.

- Recent Japanese research is described involving the feeding of antibiotics and tea polyphenols in reducing excretion of odor-causing compounds.

- Preliminary investigations have indicated that certain polysaccharides, when fed to swine, cause an increase in the percentage of *Bifidobacteria* in the animals' gut with a resulting 2-2.5 fold decrease in indole and skatole concentrations.

Nevertheless, Miner (1995) summarizes that overall, "introducing feed additives to bind ammonia, change digestion pH, affect specific enzyme activity, and mask odors has met with very little success". Other sources report that a sarsaponin extract from the *Yucca schidigera* plant reduces ammonia in swine waste while passing harmlessly through the animal's digestive tract (Swine Odor Task Force, 1995). Additional research on sarsaponin, and how it may reduce ammonia liberation from manure, is reviewed in Miner (1995).

The Pig Improvement Company has indicated it has been successful in decreasing odors through the addition of dietary supplements to feed (PIC, 1994); however, such feed formulas are generally proprietary.

More research is needed to identify groups of bacteria in the pig's cecum and colon and their metabolic relationships, to identify factors influencing the microbial populations, and to determine feed ingredients (including enzymes, bacterial agents, and antibiotics, etc.) that will control optimal microbial metabolism in the digestive system. The principal aim of such research needs to be to enhance animal growth and productivity and minimize nutrient excretion and odors in fresh and stored manure (Miner, 1995).

Waste additives

Waste additives are chemical or biological materials added to manure or waste water. There are many such commercial products, for which this document makes no claims or endorsements. Commercial additives must be used discriminatingly, as they often have narrow applications, and some may add unwanted "inert" materials such as salts to the wastewater stream. Additives should not be a substitute for good design and odor management practices.

Commercial additives may control specific parameters such as ammonia and hydrogen sulfide from the array of odorants. However, objective information regarding the actual impact of the products on odor, as perceived by smell, is either not available, is based on testimonials, or is subjective in nature; prospective purchasers of additives should contact their state's land grant institutions and/or representative commodity organizations concerning the latest information on additives (Miner, 1995). Miner et al (1995) describe a procedure proposed to evaluate the effectiveness of additives for odor control. They note that although the products tested using the procedure did not achieve the degree of odor control that was desired, there was agreement by three independent testers as to the extent to which products were effective.

Biological additives. Biological additives, or digestive deodorants, generally contain mixed cultures of enzymes or microorganisms designed to enhance the degradation of solids and reduce the volatilization of ammonia and/or hydrogen sulfide. The microorganisms are meant to metabolize the organic compounds contained in the manure. Digestive deodorants may act to inhibit selected biological or digestive processes by changing the enzyme balance (ASAE, 1994). Most digestive deodorants are applied directly into the manure collection area and/or the lagoon.

Adding lactic acid bacteria to lagoons can reduce pH which thereby reduces ammonia emissions during storage and application; however, this method severely reduces nitrogen reduction and transformation in anaerobic lagoons (Swine Odor Task Force, 1995). Products that contain active bacterial cultures hold the most promise for working with lagoon bacteria to limit odor (Safley et al., 1993). Reports indicate that digestive deodorants must be added frequently to allow selected bacteria to predominate (Sweeten, 1991).

Miner (1995) reviewed several studies of digestive deodorants and concluded that "the variable success measured for the effectiveness of microbial and digestive agents to control odor may be due to the inability of these products to degrade many of the compounds which collectively make up odor from a swine operation". And "supplemental microorganisms, as additives, may not readily adapt to the natural conditions in manure handling systems and are often susceptible to competition from the naturally occurring indigenous microbial populations".

Chemical additives. Chemical additives, or oxidizing agents, act by chemically altering odorous compounds or enzymes. They also may kill the bacteria which produce the volatile organic malodorous compounds. Examples of oxidants are hydrogen peroxide and potassium permanganate. Miner (1995) reviewed studies which found these and other chemicals effective in reducing swine odors. For example, low concentrations of ozone (one gram per liter) were found to reduce swine manure slurry odors, partly by the destruction of phenolic metabolites in the slurry (Yokoyama, 1994). Lindvall, Noren and Thyselius (1974) found that ammonium persulphate showed a good effect in reducing swine manure odors.

Additives which lower the pH of manure will reduce volatilization of ammonia and hydrogen sulfide. Miner (1995) cites several studies which indicate that triple superphosphate fertilizer mixed with swine manure reduces ammonia emissions, and that the addition of lime to liquid hog manure can control the release of hydrogen sulfide in liquid hog manure. Sweeten (1991) reported that published studies have shown potassium permanganate (100-500 ppm), hydrogen peroxide (100-125 ppm), and chlorine as having the capability of controlling hydrogen sulfide emissions.

Long term use of chemical additives may require large amounts and frequent applications, making their continual use expensive and potentially damaging to water supplies. Potassium permanganate, hydrogen peroxide and paraformaldehyde are expensive and dangerous to handle (Miner, 1995).

Masking agents. Masking agents cover one smell with another. As a result, they must be strong, and may be almost as objectionable as the swine odor. Masking agents are normally used as vaporized material injected into the air at the leeward edge of the odor source, such as a lagoon. Masking agents may be prohibitively expensive if used for more than small amounts of waste (Kreis, 1994). Agents may be applied directly to waste water, in which case, for non-vaporized masking agents, Miner (1995) concluded that "the organic chemical composition of most masking agents makes them susceptible to degradation by the microorganisms indigenous to manure". And thus, "the odor control capacity of most masking agents and counteractants may be too short lived for practical use in swine production environments".

Adsorbents and absorbents. These are biological or chemical materials that can collect odorous compounds on their surfaces (adsorb) or interiors (absorb). Examples are Sphagnum peat moss, sawdust, rice straw, sodium bentonite, and certain natural zeolites. Absorbents with a large surface area, such as sphagnum peat moss, have been found to reduce odor in some lagoons (Swine Odor Task Force, 1995). Miner (1995) indicates that research has found that "the concentration of peat moss could be lowered to one percent for effective odor control when calcium carbonate was added to the manure slurry". Floating organic lagoon covers, and soil biofilters, are other examples of the use of odor absorbing materials.

7. ODOR EVALUATION CHECKLIST

The following odor evaluation checklist lists management factors that influence odor production in swine CAFOs. In the "desirable criteria" column are actions or practices which implement the various management factors. The material in the checklist is based on review of the literature (see Section 9, References) and peer review. Management factors are listed alphabetically, with a bit more detail and other sources of information, in Section 8, Glossary of Odor Management Practices.

This checklist may be expanded or revised over time. For example, more effective methods may be introduced, or a "weighting system" for the criteria may be added. However, at present, it is being considered primarily as a supplemental screening tool for evaluating odor impacts in the new source NEPA review process.

Barring unusual circumstances, the potential for swine CAFO odor impacts significantly decreases if there are no sensitive receptors (e.g. residences, schools, hospitals, nursing homes, etc.) within four to five miles, and possibly less for small or well designed operations. However, odor impacts are possible, depending on climatological or other conditions, when separation distances become closer and/or individual CAFOs become more concentrated (i.e., within two miles of each other).

Use the list by checking off those instances where "desirable criteria" are being or are proposed to be used. Keep in mind that the list is skewed towards (and thus "desirable" refers to) those practices thought most likely to have the potential to reduce swine odors. If desirable criteria as listed are not being used, or other desirable criteria are applicable for reducing swine odors, additional rows and the comment column are available for indicating how other methods would be effective, including literature citations or other references or explanations as appropriate.

Additional expertise and advice may be available from agricultural engineering specialists at land grant universities, at offices of the U.S. Natural Resource Conservation Service (formerly Soil Conservation Service), and through EPA's Compliance Assistance Center, Region 7, Kansas City, KA.

The checklist is organized in the following manner.

Odor Evaluation Checklist

MANAGEMENT FACTORS:	DESIRABLE CRITERIA (where applicable):	✓	COMMENTS:
FACILITY SITING			
Distance from residences	At least 2 miles and preferably 4 miles for larger facilities:		
Distance from other CAFOs	Several miles apart, to reduce the potential for cumulative impacts:		
Lagoon location	Lagoons as close to animal housing and as far from neighbors as practicable: All else being equal, larger lagoons, and lagoons with relatively high volatile solids loading rates, should be farther from neighbors:		
Location relative to climatic data	Downwind from closest neighbors, relative to wind direction frequencies:		
Orientation of facilities	Oriented to minimize exposure to prevailing winds:		
Vegetative barriers	Used between neighbors and potential odor causing facilities, such as: animal housing: storage/treatment: land application sites:		
ANIMAL HOUSING: Open swine feedlots			
Organization	Dunging promoted in easily cleaned areas: Sun angle favorable for drying, e.g., feed, water sites: Adequate spacing per head: Shades oriented north-south and/or slotted:		
Drainage	If applicable, open lot surfaces, alleys, and ditches graded to shed water rapidly: Slopes of 2% or greater away from feeding areas: Concrete pads extending at least 8 feet away from feeding areas and watering facilities:		
Lot cleanliness	Manure and water frequently collected from feedlot surfaces and runoff collection systems: Spilled feed and manure removed from beneath fence lines and feeders:		

MANAGEMENT FACTORS:	DESIRABLE CRITERIA (where applicable):	✓	COMMENTS:
ANIMAL HOUSING: Confinement buildings			
Building interior	Smooth, easily cleaned surfaces with a minimum of cracks, crevices:		
Building cleanliness, dust control	Regular removal of settled dust and manure from surfaces (e.g., floors, walls, fans): Bedding replaced frequently: Odor potential minimized in feed delivery (e.g., enclosed system; no old food around feeding area):		
Ventilation	Under-floor manure storage pits vented: Fresh air intakes located away from dust sources, manure pits:		
Manure management	Frequent removal, using fresh or well-treated water: Flushing systems flushed as frequently as necessary each day for odor control: Pit recharge systems partially drained, refilled at least weekly:		
Exhaust release, orientation, treatment	Alternatives include: elevated source release (stacks): Exhaust air directed up or away from neighbors: Air treatment (conventional air scrubbers, biofilters and bioscrubbers; or thermal incineration/catalytic oxidation):		
ANIMAL HOUSING: Both			
Dead animal disposal and storage	Prompt rendering, burial, incineration, or composting: Refrigerated if carcasses not disposed of before decomposition begins:		
Animal cleanliness	Animals clean of manure to extent practical:		
Rations	Balanced to minimize odor where appropriate (proven methods used, including alternative foodstuffs selection and proportions where knowledge exits):		

MANAGEMENT FACTORS:	DESIRABLE CRITERIA (where applicable):	✓	COMMENTS:
WASTE STORAGE & TREATMENT: Storage (external to buildings)			
Exposure to atmosphere	Temporary liquid or slurry manure storage covered if inadequate site isolation:		
Capacity	Adequate to provide disposal flexibility:		
Pumping	Agitation pumps discharge below water surface:		
Solid manure storage	Moisture minimized (less than 50 %); see Composting, Dehydration and Storage entries in Index:		
Separated solids	Removed promptly and composted and/or disked or injected into the soil:		
WASTE STORAGE & TREATMENT: Lagoons			
Capacity	Adequate to allow volatile solids loading rates which minimize odor: Sufficient (e.g., 6 months) to allow effluent removal to coincide with advantageous weather conditions:		
Start-up	Start in late spring or summer; minimum treatment volume filled with water prior to introducing manure; loading gradually increased to design loading rate:		
Operation	Lagoon not overloaded above design volatile solids loading rate: Reduced loading rates in winter if feasible: Nearly constant level of suspended solids and dissolved minerals: Daily or frequent loading to avoid "shock" loading and upset:		
Aerobic lagoons	Aerators sized to provide sufficient oxygen to satisfy the five-day BOD and nitrogenous oxygen demand, or the majority of the COD:		
Effluent removal	Lagoon not pumped below minimum design volume(40-50% of active volume left): Pumped from second or tertiary stage lagoon if available: Removal pumps located as far as possible from inflow line and above the designed sludge storage volume: In cooler climates, lagoon liquid only removed during warmer months, no more than 25% of lagoon volume removed in the late fall to maintain sufficient bacteria:		

MANAGEMENT FACTORS:	DESIRABLE CRITERIA (where applicable):	✓	COMMENTS:
WASTE STORAGE & TREATMENT: Other treatment methods			
Digesters	Operated to maximize rate of organic matter stabilization and odor control (e.g., loading rate, retention time and temperature):		
Composting	Ammonia emissions controlled: Frequent turning (e.g., weekly) or mechanical forced aeration, and several seeks or months (8-16 weeks) allowed:		
Alternative systems	Closely monitored, as methods are experimental, rare, or site specific, requiring careful, justifiable design:		
LAND APPLICATION			
Timing	Weekends and holidays avoided: Solid manure or slurry applied within four days of excretion:		
Location	Land application near residences minimized: Use made of vegetative screens:		
Weather conditions	Utilization of winds blowing away from populated areas to dissipate and dilute odors: Application during rising air conditions:		
Strength of waste water	Diluted with fresh water if possible:		
Sprinkler system	Low pressure system: Low trajectory or overhead system used: Extra-fine spray avoided:		
Soil injection	Injected immediately behind tractor: High water tables, highly permeable soils avoided:		
Soil incorporation	Plowed or disked immediately (less than 3-6 hours) after application:		
Irrigation	Irrigation with untreated slurry avoided: Waste water exposure, splashing minimized: Plowed immediately:		

8. GLOSSARY OF ODOR MANAGEMENT PRACTICES

Air scrubbing, conventional. These systems use chemical oxidation (as opposed to oxidation through combustion) or mist and packed scrubbers (aqueous solutions). For adequate odor abatement, several stages or scrubbers may be needed (Miner, 1995). Safely, et al (1993) considered wet scrubbing (fogging, misting, or spraying) inefficient compared to other methods of cleaning or filtering exhaust air. See also: Exhaust air treatment; Biofilters and bioscrubbers; and Thermal incineration/catalytic oxidation.

Aerobic digesters. Incorporating oxygen containing air into liquid or slurry manure can promote aerobic treatment, which is a less odorous process than anaerobic treatment (Miner, 1995). Continuous aerobic culture treatment for the purpose of odor control is affected by treatment time, temperature, dissolved oxygen level, and insulation factors (Miner, 1995). Aerobic treatment systems can be designed to meet defined objectives in terms of odor control (Miner, 1995).

Aerobic lagoon design and management. Aerobic decomposition is effective in reducing odor-causing fatty acids and other overall odors (Swine Odor Task Force, 1995). Aerobic lagoons require free oxygen to sustain the aerobic bacteria which process wastes with less odor than anaerobic bacteria (Safely, et al., 1993; ASAE, 1994). Mechanical aeration of liquid manure in lagoons is an effective odor control method (Sweeten, 1991). Aeration rapidly reduces hydrogen sulfide emissions from swine manure, but less volatile and less offensive compounds such as phenols persist (Sweeten, 1991). Aerated lagoons are an alternative when space constraints limit the area available for manure storage or to reduce an odor nuisance problem in higher populated areas or in closer proximity than anaerobic lagoons, especially if the latter are overloaded (Veenhuizen, 1996). Aeration systems have been shown to reduce odor emissions up to 75% to 86% and reduce odor intensity and offensiveness (Veenhuizen, 1996).

An aerated lagoon properly designed and operated will produce odors of lower intensity and offensiveness, but is relatively expensive to operate (Veenhuizen, 1996). The required oxygen concentration can be achieved by either designing the lagoon to be lightly loaded and shallow (maximum liquid depth of 5 feet) for maximum oxygen transfer or to use mechanical aerators (Safely, et al., 1993). Both types of lagoons require the separation of liquids and solids as a pretreatment step (Swine Odor Task Force, 1995). Aerators should be sized to provide sufficient oxygen to minimize odor production potential and promote decomposition of organic matter (Safely, et al., 1993). Oxygenation capacity sufficient to satisfy at least the five-day biochemical oxygen demand (BOD), or the majority or all of the chemical oxygen demand (COD) plus the nitrogenous oxygen demand, is generally required (ASAE, 1994). Aerobic decomposition requires the separation of liquids and solids (Swine Odor Task Force, 1995).

Anaerobic digesters. Anaerobic digesters are enclosed tanks with controlled conditions wherein manure in slurry form is biologically degraded (Miner, 1995). There is very little odor released from a properly managed anaerobic digester (Miner, 1995). Provided proper volatile solids or COD loading rates, adequate retention time and specific temperatures (e.g., 95°F or 135°F), a well-controlled anaerobic digestion process will degrade the vast majority of compounds that contribute to odors (Vetter, 1994). The resulting sludge is much less odorous than raw manure (Vetter, 1994; Miner, 1995). Odor emission rates upon land application are reduced by 90 percent as compared to pit-stored slurry

(Sweeten, 1991). Anaerobic digestion provides a low-odor material for land application (Fulhage, 1996b). Surface spreading of anaerobically digested slurries reduces odor emissions during the first six hours following application by between 70% to 80% compared to surface spreading untreated slurries (Miner, 1995). Anaerobic digestion also reduces the time for odor dissipation from 72 hours to 24 hours (Sweeten, 1991).

Anaerobic lagoon design and management. Anaerobic lagoons are less odorous than manure storage pits (Miner, 1995). Lagoons usually have the largest surface area per animal of all storage structures. This implies a significant potential for odor release (i.e. emission rate) if the lagoon is not functioning properly. Design and management considerations have a great impact on the odor generation of lagoons (Fulhage, 1996b). Odor of low intensity and offensiveness will be detectable from well-designed and managed anaerobic lagoons (Veenhuizen, 1996; Miner, 1995). An anaerobic lagoon will produce minimum odors when acid-forming and methane-forming anaerobic bacteria are in balance; rapid fluctuations in temperature may be avoided by making the lagoon as deep as possible (Harmon and Privette, 1991). Odor emissions are usually greatest during the seasonal changeover from winter to spring conditions (sometimes fall) and during start-up (ASAE, 1993; Veenhuizen, 1996). Lagoons should be pumped down to minimum design volume on average once, twice or three times a year, but not completely emptied unless excess sludge is to be removed (at infrequent intervals) from the bottom (Miner, 1995; Fulhage, 1996b).

Anaerobic lagoon loading rates. The "health" of an anaerobic lagoon is controlled primarily by the volatile solids loading rate (Safely, et al., 1993). Limited field research indicates that odor may be proportional to lagoon loading rates (Swine Odor Task Force, 1995). Loading rates should not exceed the biological limits of the bacteria (Veenhuizen, 1996). Primary overloading problems can be caused by expanding animal numbers, slug loading, concentrated waste input, inadequate dilution water, or conditions that are not favorable for methane forming bacteria (cold temperatures, low pH) (Veenhuizen, 1996). The result is incomplete anaerobic decomposition and can lead to stronger odors from the lagoon and during land application in winter and spring months (Miner, 1995; Veenhuizen, 1996).

As a rule, reducing the volatile solids loading rate reduces the potential for odors (Safely, et al., 1993). Loading rates during the winter should be reduced to prevent or reduce lagoon "turnover" - defined as "very vigorous activity during the spring due to incomplete metabolism of material during cooler periods such as winter" (Safely, et al., 1993). Smaller daily or weekly loading results in best performance; this assures a continuous food supply for the bacteria and helps keep the bacteria populations in balance (Safely, et al., 1993, Fulhage, 1996b). A two or three stage lagoon system may improve management capabilities and thereby lower odor emissions as compared to a single step system.

Anaerobic lagoon startup. Lagoons will have elevated odor levels until reaching maturity, which usually takes at least one year. Lagoons should be carefully managed during startup to minimize potential odors. Lagoons should be started in the late spring or summer to allow the bacteria opportunity to become established since they grow and reproduce faster at warmer temperatures (Safely, et al., 1993; Fulhage, 1996b). The minimum treatment volume or two-thirds of the lagoon should be filled with water prior to introducing manure (Fulhage, 1996b). Manure loading should be gradually increased over a 2 to 3 month period. Rapid loading of an immature lagoon will increase odors (Safely, et al., 1993).

Anaerobic lagoon storage volumes. Anaerobic lagoons must have adequate capacity (i.e., low volatile solids loading rate) to produce relatively little odor (Sweeten, 1991; Sweeten, 1995b; Fulhage, 1996b). Design criteria have been developed based on the volatile solids loading rate, which is proportional to the volume per pound of liveweight (Sweeten, 1991; ASAE, 1993). Lagoon capacity should be sufficient to allow liquid removal to coincide with beneficial nutrient utilization on crops and advantageous weather conditions (Safely, et al., 1993; Veenhuizen, 1996).

Animal shades. Odor control approaches for feedlots include keeping uncollected manure relatively dry (30-50% moisture content) (Sweeten, 1990). Shades in open feedlots should be oriented north and south and/or slotted so that the sun can reach all parts of the lot during the day to help dry manure and cause livestock to dung over a broader area.

Biofilters and bioscrubbers. Biofilters use compost, peat, bark, heather, or soil to filter air. Soil filters with perforated pipe in a shallow soil bed have proved effective for scrubbing odors from building exhaust air (Sweeten, 1991; Miner, 1995). A 99.9 percent odor reduction (Miner, 1995), 52 to 78 percent ammonia reduction, and 46 percent removal of organic constituents (Sweeten, 1991) in confinement building exhaust air has been reported using soil filters.

Bioscrubbers combine biological and chemical treatment, and are self-regenerative. Bioscrubbers last one to seven years and are cheaper than conventional scrubbers using chemical oxidation. Counter-flow single stage bioscrubbers can reach an ammonia removal efficiency of 70 to 80 percent (Miner, 1995). Biofilters and bioscrubbers both require a system to force air through the treatment medium and management to maintain optimal microbial conditions of temperature, pH, and moisture (Miner, 1995).

Biofiltration and wetlands. Systems using biofiltration that slowly filter waste through biologically active bacteria have been shown to remove up to 90% of volatile organics; however, this method can be prohibitively expensive to construct and is subject to frequent clogging and the subsequent need for maintenance (Swine Odor Task Force, 1995).

Constructed wetlands are shallow (12"-18" water depth), essentially level earthen basins that are designed for waste water treatment. They are populated with aquatic plants such as cattail and bulrushes. The plants serve as a filter to remove nutrients through a variety of physical, chemical, and biological processes. Wetlands can be used to further treat effluent from lagoons if the solids and ammonia concentrations are not too high. Some dilution of lagoon liquid is typically required prior to discharge into constructed wetlands. Effluent from constructed wetlands must be collected for recycle or land application. The primary benefit of a constructed wetland is that the reduction of nutrients means less land will be required for disposal of effluent (Safely, et al., 1993). Other benefits may include improved quality of water for recycle flush systems and lower odor upon land application.

Building cleanliness. Surveys have shown that building hygiene plays a big part in aerial dust concentrations (Safely, et al., 1993; Veenhuizen, 1996). Buildings with clean pen floors, walls, fans, and regular removal of settled dust and litter usually have less dust in the air (Safely, et al., 1993; NPPC, 1996). Frequent cleaning of interior surfaces with water can substantially reduce odors (Swine Odor Task Force, 1995). Keeping surfaces dry and clean of manure will reduce odors from anaerobic decomposition (Miner, 1995). The pen floors are a source of fecal dust once the manure and feed is dried out (Safely, et al., 1993; NPPC, 1996). Keeping feeding areas free from decomposing feed will reduce odors and dust. Liquid feed that putrefies is especially odorous (Miner, 1995).

Building interior construction. Interior construction utilizing smooth surfaces with a minimum of cracks and crevices (e.g., steel or aluminum instead of concrete slats) tends to reduce the buildup of odor-carrying particulates, such as dust (Swine Odor Task Force, 1995).

Building, storage, and treatment facility orientation. Odor is carried downwind and is typically diluted in a vertical direction with very little dispersion by fanning out in the horizontal direction. The result is that the area affected by odors downwind is often not much wider than the odor source. By orienting odor sources to minimize exposure to the wind (i.e., the maximum length of the facility oriented in the same direction as the dominant wind), fewer people are likely to be affected when odor is transported downwind, since the odor plume is narrower (Miner, 1995; NPPC, 1996).

Climatic data. Prevailing winds should be considered in site selection to minimize the frequency of odor transport to housing developments or neighboring residences (Miner, 1995). Odor dispersion is partly accomplished by selecting a site that takes advantage of wind direction frequency and atmospheric stability data (Sweeten, 1995b). Unique meteorological conditions, such as air inversions, affect odor transport (Miner, 1995).

Composting. Composting is a natural biological process that requires air, moisture, and the right proportion of carbon to nitrogen (Veenhuizen, 1996). Composting is usually used for solid manure and separated manure solids, although there is also a process for liquid composting for thermophilic aerobic treatment which has been used in Europe with almost odorless results (Miner, 1995). Advantages of compost are: low odor in finished compost; dry material which can be bagged, piled, and spread; reduction in fly breeding potential, viable weed seeds and pathogens (Sweeten, 1980; Veenhuizen, 1996). Requirements: odor control strategies due to high levels of ammonia loss, land area for compost piles, several months to a year for compost time, composting structures or vessels and mechanical aeration to control the composting process and speed up composting (Veenhuizen, 1996). Composting of manure solids can be used to stabilize the waste before land application (Veenhuizen, 1996).

Covers. See Storage covers.

Dead animal disposal and storage. Prompt dead animal disposal in very important in abating odors. Rendering, burial, and incineration are normally approved methods of handling dead animals (Miner, 1995). Refrigeration is sometimes used for storage of dead animals until they are picked up for disposal (Miner, 1995). Composting dead swine is very cost effective, simple, and has no negative environmental impacts (Fulhage, 1994).

Deep pits. Deep pits under slotted floors are not satisfactory in abating odors. Recent research showed that total slotted floors with deep pit and long-term storage generated the most ammonia of other manure systems evaluated (including systems with partially slotted floors, partially slotted floors combined with a sloping floor under the slats with frequent flushing, partially slotted floors with collection in about 4 inches of flushing water, and a "pull plug with recharge" or "fill and empty" or pit recharge system) (Safely, et al., 1993). Longer storage means increased odor and ammonia generation (Safely, et al., 1993; NPPC, 1996). A building with partially slotted floor and a manure pit exhibits ammonia emissions which can be 20% lower than a total slotted building (Safely, et al., 1993). Deep pits are a safety hazard to pigs and workers when the slurry is agitated without adequate ventilation.

Reduction of odor in deep manure pits can be accomplished by: 1) developing an aerobic system, 2) enhancing anaerobic conditions, 3) stopping microbial activity. Proper conditions in a pit for anaerobic decomposition will reduce the buildup of both solids and toxic gas. However, proper anaerobic decomposition is difficult to attain because of the high loading rate, solids content, ammonia content, buffering capacity, and low temperature. Adding water to the pit reduces ammonia concentrations in the urine and enhances anaerobic conditions. Lowering pit pH can retard microbial activity (and thus gas production), and can be accomplished through the addition of nitric acid (Safely, et al., 1993).

Dehydration. Dehydration is one common technique for inhibiting anaerobic decomposition, thereby reducing odors in solid manure. When the moisture content of manure is lowered to 50 percent or less (preferably 30%), the manure is sufficiently porous to permit air diffusion and to preclude anaerobic decomposition.

Digesters. Odor control is a substantial benefit of digesters (Miner, 1995). There are three types of digesters: batch, complete mix, and plug flow (Fulhage, 1996a). The batch digester is loaded in a single charge and does not accommodate a continuous flow of manure. The complete mix digester is characterized by continuous feeding and mixing to enhance bacterial performance. The plug-flow digester is an elongated tube in which manure solids are introduced to one end and allowed to proceed to the other end with no mixing while digestion takes place. Retention times of 15-20 days are typical for anaerobic digesters (Fulhage, 1996a).

Disinfection. Chemical disinfection can be used to inhibit anaerobic decomposition in liquid manure or separated solids just prior to land application, though the effect is very temporary. Chlorine, lime, formaldehyde, and other chemical disinfectants have been used, but costs may be unreasonable in the quantities required (ASAE, 1994).

Drainage. Open feedlots should include sufficient drainage to minimize puddling and wet surfaces. For open feedlots, manure treatment for odor control consists of maintaining aerobic conditions to the extent possible. All pens should be well drained (e.g., uniform slopes of 2% to 5% away from feeding troughs). Keeping the feedlot surface, alleys, and ditches cleaned and graded to shed water rapidly minimizes anaerobic conditions after rainfall events (Sweeten, 1991). Pen-to-pen drainage should be avoided in favor of discrete pen drainage.

Dust control methods. Odors from volatile fatty acids and other odor-related compounds attach to and can radiate from and be transported on feed dust, dander, and other airborne particulates in confinement buildings (Swine Odor Task Force, 1995). See: Feed delivery, air flushing, animal handling, building cleanliness, interior construction, ventilation, and ventilation rates.

Exhaust air treatment. Filtering exhaust air can reduce odor emissions from animal confinement buildings up to 60%. Filter materials include cloth, charcoal, ozone, soil filters, bioscrubbers, biofilters, and ionization (Miner, 1995). Thermal incineration/catalytic oxidation are also exhaust treatment options. See: Air scrubbing - conventional; Biofilters and bioscrubbers; Thermal incineration/catalytic oxidation.

Exhaust release and orientation. Stacks that release odor above the maximum height of buildings or trees can be used to release building exhaust air higher in the atmosphere to help disperse and dilute odors (Miner, 1995). Hoods can be used to direct air away from neighbors. Hoods directing exhaust air up will promote odor dispersion and dilution (NPPC, 1996). Ventilation fans should be oriented to exhaust air away from neighbors (NPPC, 1996).

Facultative lagoons/surface aeration. Facultative lagoons combine anaerobic and aerobic bacteria treatment (Safely, et al., 1993) by "capping" an anaerobic lagoon with an aerobic surface (NPPC, 1996). Mechanical aerators can be used to aerate the lagoon surface. This treatment system can be utilized to reduce odors liberated to the atmosphere (Miner, 1995). Sweeten (1991) reported that aerating only the top third or half of swine lagoon contents proved successful in abating odors; the National Pork Producers Council (1995) suggested aerating the top 6-12 inches of the lagoon surface. Surface aeration significantly reduces power requirements as compared with complete aeration (NPPC, 1996; Sweeten, 1991).

Feed. See rations.

Feed delivery. The delivery of feed produces spikes in the dust concentration of a building. Dust can be reduced by enclosing the dust cloud caused by feed delivery with feed drop tubes and feeder lids (Safely, et al., 1993; NPPC, 1996). Pelleted feeding and wet feeding reduce dust levels. Additives can be introduced to dry feeds to reduce their dust generating potential. These additives can be soybean oil, canola oil, rapeseed oil, or animal fats (Safley, et al., 1993; Veenhuizen, 1996).

Feedlot organization. The organization of feedlots has a strong impact on odor and dust production. For example, feedlots can be organized to promote dunging for easy manure collection by placing watering troughs away from areas of heavy activity (i.e. eating and sleeping areas) (NPPC, 1996). Orienting feedpens for maximum sunlight exposure on the feedlot surface minimizes moisture and anaerobic conditions (Sweeten, 1991).

Flushing liquid. Many producers recycle lagoon liquid for pit flushing in order to reduce the amount of water added to a treatment system and consequently reduce the quantity of lagoon liquid to be land applied and thus the odor exposure (Safely, et al., 1993). However, using fresh water to flush pits will reduce odors in buildings during flushing (NPPC, 1996). Second stage lagoon effluent is preferable to primary lagoon effluent for flushing due to lower odor potential and solids content.

Flushing systems. Flushing systems generate less odors than any other manure handling system for confinement buildings due to very frequent manure collection. Flushing or draining manure prior to the onset of manure decomposition is recommended 3-4 times daily for controlling ammonia generation (NPPC, 1996). Frequent manure collection using flushing systems helps reduce odorous gases and eliminate anaerobic storage conditions in confinement buildings (Sweeten, 1991; Sweeten, 1995b; Veenhuizen, 1996). A partially slotted floor combined with a sloping floor under the slats from which manure is flushed several times a day can have ammonia emissions that are 30 percent below that of a deep pit system; greater odor reductions can be achieved when manure is collected under a slotted floor in about 4 inches of flushing water and changed 3-4 times daily (Safely, et al., 1993).

Irrigation. Miner (1995) states that surface irrigation techniques are less odorous than sprinkler irrigation. However, because ammonia volatilization is much less with surface irrigation, more land is needed to prevent ground water pollution by nitrate. Irrigation of manure slurry from pits can be very odorous and should be carefully managed if this method is used. Irrigation on highly erodable land or on hard-pan clay soils should be managed very carefully to avoid any runoff. Irrigation with secondary or tertiary stage lagoon effluent is likely to produce lower odor than primary lagoon effluent.

Low pressure irrigation systems (for example, 15 to 20 psi versus 80-90 psi for high pressure systems) are likely to be less odorous than high pressure systems because of less drift downwind. Center pivot systems can direct spray downwards, minimizing aerosol drift. The low pressure reduces ammonia stripping and associated odors, and water is directed down towards the crop rather than ejected into the air and exposed to winds, as with high pressure, high trajectory systems. Veenhuizen (1996) recommends a minimum buffer zone of 50 feet from roads and 200 feet from residences when the wind is blowing away from them, and a larger buffer when the wind is towards them. Veenhuizen (1996) also recommends windbreaks of two to three rows of trees to reduce aerosol drift.

Lagoon effluent removal. Aerobic or anaerobic lagoons should not be pumped below the level that has been determined as the minimum design volume to ensure that sufficient volume is available for adequate manure treatment and to retain the necessary active bacterial culture. As a rule, 40-50 percent of the active lagoon volume should be left in the lagoon. In cooler climates, lagoon liquid should only be removed during the warmer summer months. More than 25% of the total volume of a lagoon should not be removed in the late fall to maintain sufficient bacterial populations. In warm, humid climates, lagoon liquid can be removed throughout the year. Removal pumps should be located as far as possible from the inflow line to allow for maximum treatment (Safely, et al., 1993).

Lagoon location. Lagoon location is one of the most critical aspects of successful lagoon operation. Before locating a lagoon, the entire waste management system (lagoon, land application equipment, crops and land to receive lagoon nutrients) should be planned and evaluated (Safely, et al., 1993). The following should be considered when locating a lagoon: sufficient land in reasonable proximity to accommodate the nutrients to be periodically removed and applied; prevailing wind direction and air drainage patterns (air follows flow lines similar to water when winds are calm and humidities are high); likelihood of future nearby housing development (Safely, et al., 1993).

Land application. Studies indicate that waste water disposal is the basis for a majority of odor nuisance complaints from swine operations, and that land application is the primary method of disposal (Miner, 1995). Minimize the number of days of land application near neighboring residences; this may require more storage capacity (Miner, 1995). Larger lagoons increase operator flexibility as to timing of application. Avoid land application when the wind would blow odors toward populated areas or nearby residents or businesses (ASAE, 1994).

ASAE (1994) recommends the following: spread or apply solid manure or slurry within 4 days of excretion if possible to reduce time in anaerobic storage; apply manure uniformly and in a layer thin enough to insure drying in 5 days or less and to prevent fly propagation in warm weather; spread or apply manure in the morning when air is warming and rising rather than in the late afternoon; avoid spreading or applying manure immediately before weekends and holidays when people are likely to be engaged in nearby outdoor and recreational activities; use available weather information to best advantage. Turbulent breezes will dissipate and dilute odors. Rain will remove the odors from the atmosphere(ASAE, 1994).

See also Irrigation.

Liquid manure storage. See Storage.

Lot cleanliness. Odor control approaches for feedlots include maintaining a minimum inventory of animals (Sweeten, 1991). Frequent harvesting of surface manure from feedlot surfaces will reduce moisture absorption, accelerate drying, and restore aerobic conditions (Sweeten, 1995b). Accumulated manure on lot surfaces will have more odor during warm, wet weather than manure in storage (Veenhuizen, 1996). Prompt collection of water and solids from runoff holding ponds and sedimentation basins will reduce organic solids loads and restore less odorous conditions more quickly (Sweeten, 1991; NPPC, 1996; Sweeten, 1995b). Keeping the feedlot surface, alleys, and ditches cleaned and graded to shed water rapidly minimizes anaerobic conditions after rainfall events (Sweeten, 1991). Preventing water leaks and watering system maintenance to prevent spillage are considered effective odor control measures (Sweeten, 1991; Sweeten, 1995b).

Oxidation ditches. Dale et al (1975) found that oxidation ditches under slotted floors are not completely satisfactory in abating odors. Sweeten (1991) cites research that found mechanical aeration of liquid manure in oxidation ditches to be an effective odor control method.

Pit recharge. Pit recharge systems generate decreased odors compared to either deep or shallow pits. The NPPC recommends flushing pit recharge systems every 5-7 days. Using fresh water to flush pits will reduce odors in buildings during flushing (NPPC, 1996). Pit recharged systems of under-floor swine manure pits have been found to control odors and gas buildup (Miner, 1995). Frequent manure collection using pit recharge systems helps reduce odorous gases and eliminate anaerobic storage conditions in confinement buildings (Sweeten, 1991; Sweeten, 1995b). Ammonia emission can be reduced by 60% using pit recharge systems (Safely, et al., 1993). Using "pull plug with recharge" or "fill and empty" recharge systems of manure removal, ammonia emissions can be reduced by 70% of that from the deep pit (Safely, et al., 1993). These latter principles reduce liquid turbulence thereby reducing odor emissions by locating a drain plug for slurry and liquid removal below the effluent surface (Safely, et al., 1993).

Rations. Phase feeding, split sex feeding, pelleted feed, high moisture feed, and reducing ration crude protein levels along with adding synthetic amino acids can reduce ammonia emissions. Substances added to the slurry or to the feed to reduce the release of ammonia from the manure have not yet been tested over long periods and their effectiveness is still debated. Feed additives based on yucca extracts will reduce urease activity in manure and potentially bind ammonia preventing its release (Safely, et al., 1993).

Runoff collection. Settling basins and holding ponds for collected runoff will reduce odors (NPPC, 1996; Sweeten, 1991) and should be emptied as soon as possible after rains (Miner, 1995).

Scraper systems. Surface scrapers always leave behind a film of urine on the surface, and thus are not completely satisfactory in abating odors or controlling ammonia emissions (Safely, et al., 1993). Scraping pits with 2 inches of water will decrease dust and odor in buildings (NPPC, 1996). Frequent manure collection using cable scraping will help reduce odorous gases and eliminate anaerobic storage conditions in confinement buildings (Sweeten, 1991).

Shallow pits. Shallow pits provide short term storage. Decreased storage time and frequent cleaning translate to decreased odors compared to deep pit systems (NPPC, 1996).

Slurry manure storage. See Storage.

Soil incorporation. Incorporate manure into the soil during or immediately after application. This can be done by 1) soil injection or 2) plowing or disking. These practices not only minimize the spreading of odor but also preserve nutrients and reduce water pollution potential from runoff (ASAE, 1994). Sweeten (1991) indicates that disk harrowing or plowing of surface spread manure reduces odor by 67 to 95 percent compared to surface spreading (Sweeten, 1991). Miner (1995) indicates plowing immediately after application reduces the rate of odor emission during the first hour by 85% and rotary harrowing reduces it by 45%. A reduction of 52% over 4-8 hours was achieved only by immediate plowing. No reduction in total odor emission is detected when incorporation by any means is delayed for

3-6 hours after slurry application. Incorporation of manure after spreading is less effective than injection but is helpful in reducing odors.

Soil injection. Miner (1995) indicates that injection of manure has been found to nearly eliminate odors during manure application. Odor intensity from surface application at 400 meters downwind is often perceived to be equal to that from injection at only 50 meters. Injection of slurry can reduce the odor and ammonia emissions by 80% and 95% respectively, compared to conventional splash-plate surface spreading. Best results are achieved when the injection unit is either trailed or mounted directly behind the tractor to give immediate injection. Sweeten (1991) indicates that soil injection reduces odor emissions (measured as dilutions to threshold) from liquid swine manure by 90 to 99 percent as compared to surface spreading; odor from a soil-injected manure site is about the same as from a non-manured soil surface.

Solid manure management. Well managed and sufficient amounts of straw bedding can reduce ammonia inside a building more than any other in-building solid manure management system. However, more dust and fungal spores are present in buildings with straw (Safely, et al., 1993). See also Storage.

Solids separators. Solids separation has been shown to reduce odor concentrations (Sweeten, 1995b). Common manure solids separators include: stationary sloping screens, continuous belt sloping screens, run-down screens, vibrating screens, liquid cyclones, centrifuges, auger press screens, and settling basins (Safely, et al., 1993). Because of the high maintenance requirements to empty the solids, settling basins are most commonly used for treating runoff from lots; mechanical separation is a more common separation system for flushing operations (Moore, 1989). Solids separation can exclude slowly biodegradable solids, such as straw and sawdust, and will assure that maximum volume is available in the lagoon for processing biodegradable materials (Fulhage, 1996b). Settling basins are recommended as part of an odor control strategy (NPPC, 1996).

Storage covers. Storage of liquid or slurry manure can be a source of odors (Miner, 1995). Covers on outside manure storage pits or tanks are effective means of odor control because they reduce the ventilation rate and hence the rate of odor emission (Sweeten, 1991; Veenhuizen, 1996). A concrete lid, a floating crust, or a floating membrane can reduce odor release until the storage is agitated and emptied (Veenhuizen, 1996). Rigid covers are expensive, and flexible membrane covers over large surfaces are subject to photodegradation and mechanical and wind damage over time (Sweeten, 1991). When covering manure storage, provide a port to allow gas to escape (Miner, 1995).

Storage management. Storage design and management practices that limit odor drift and promote turbulent mixing, dilution, and dissipation of odors are desirable (Veenhuizen, 1996). Adequate manure storage capacity is needed to provide management flexibility for scheduling appropriate field spreading to avoid high risk odor and spreading conditions (Veenhuizen, 1996). Plan agitation and emptying to take advantage of windy conditions and increasing air temperatures to improve mixing and dilution of odors (Veenhuizen, 1996). Placing the agitation pump to discharge below the slurry and liquid surface and maintain any crust will reduce the release of hydrogen sulfide related odors (Veenhuizen, 1996).

Odors from solid manure storage are considered somewhat minor and inoffensive, due primarily to aerobic bacterial activity. In most instances, excessive moisture in solid manure can lead to anaerobic conditions which give rise to offensive odors and fly breeding if manure is spilled outside the pen area. Adding bedding or other material to the manure or using a mechanical solids separation technique such as press rolls will remove most of the water from the manure and promote aerobic conditions. Mechanically aerating manure will promote drying and perhaps create a composting environment.

Hauling manure for land application as frequently as possible to limit storage time is suggested (Fulhage, 1996). In arid areas in which rainfall and resulting runoff from the storage area is minimal, manure can simply be stockpiled for final utilization. Cover or roof a solid manure storage facility in humid climates to exclude rainwater, which can contribute excessive moisture (Fulhage, 1996b). Drying and acidifying of waste stops the microbial action associated with odor-causing ammonia, but causes less reduction and transformation of nitrogen, thus creating an additional burden on the system of nitrogen-dispersing irrigation (Swine Odor Task Force, 1995).

Slurry manure is usually stored in earthen, concrete, or glass-lined steel structures designed to contain the manure without any seepage of discharge to the environment. Slurry manure storage facilities can be covered with natural covers, such as crusting, and artificial covers, such as biomats, plastic, and concrete lids to further limit odor emission (Fulhage, 1996b). However, the surface area available for odor release during uncovered storage of slurry manure is relatively small. The anaerobic nature of decomposition of slurry manure can cause offensive odors during agitation and subsequent land application (Fulhage, 1996b).

Liquid manure is usually stored in waste water lagoons (Fulhage, 1996b). Other common liquid manure storage structures are below-slat concrete tanks, open concrete tanks outside the building, covered concrete tanks, above-ground concrete or metal tanks, and earthen storage basins (Veenhuizen, 1996). Untreated manure stored in liquid manure storage systems is highly odorous when applied to fields. (Dale et al., 1975).

Thermal incineration/catalytic oxidation. Heating oxidizes and thereby deodorizes exhaust air, except it may produce worse odors. Catalysts allow combustion at lower temperatures, and may avoid or allow removal of hotter byproducts. This treatment system may be expensive (Miner, 1995).

Timing of application. See land application.

Topography. Topography is an important consideration for locating swine operations and will affect odor transport (Miner, 1995; NPPC, 1996). Topography and potential air inversions can affect air drainage (air follows flow lines similar to water when winds are calm and humidities are high) (Safely, et al., 1993; Miner, 1995; Sweeten, 1995b).

Vegetative barriers. There are no studies found that directly address the total impact of vegetative barriers; however, many people give testimonials to their benefit. Windbreaks can help disperse and dilute odors. Odor dispersion and transport are influenced by heavy tree cover (Miner, 1995; NPPC, 1996). Dense planting of trees may filter out dust particles which carry odors (Sweeten, 1991).

Ventilation. Ammonia releases very quickly from urine and manure that accumulates on the slats and other room surfaces. Good ventilation reduces the buildup of gases, moisture, and heat which can intensify odor (Swine Odor Task Force, 1995) and requires uniform distribution of fresh air throughout the room. Air circulation fans or distribution ducts improve the mix of indoor air during the winter. Slotted flooring or other under building tanks should be vented to prevent accumulation of noxious gases (Safely, et al., 1993). Pit ventilation is recommended (Miner, 1995). Ventilation fans which exhaust air directly from the pit will reduce manure gas concentrations in the room. Most incoming air jets in cold weather should travel across the ceiling first and then down to the floor. Ventilation intakes should be positioned away from dust sources (NPPC, 1996). Make sure fresh air doesn't enter the building through the manure pit. High speed air, in spite of pit ventilation, will "scour" ammonia gas into the room (Safely, et al., 1993).

Ventilation rates. Ammonia should be taken into account when choosing the minimum ventilation rate; since the amount of ammonia given off by manure is increased with air speed, air speeds across manure covered surfaces should be minimized (Safely, et al., 1993). Increasing airflow rates helps to eliminate dust if the relative humidity can be kept above 60% and air speeds are kept low near the dust sources; a good way to reduce dust levels is to occasionally flush the building with double the ventilation rate for about 10 minutes (Safely, et al., 1993). Odor emission rates from ventilation systems = odor concentration x ventilation rate (Sweeten, 1988).

Waste water lagoon withdrawals. Odor can be reduced by minimizing the disturbance of anaerobic lagoons, from which odorous compounds volatize rapidly. The Swine Odor Task Force (1995) indicates that fill pipes should be located below the lagoon surface and submersible pumps providing waste water for land application should be placed so as to minimize surface disturbance, but never so low as to agitate the bottom layer of anaerobic sludge. The use of anti-siphon vents where applicable can also reduce disturbance in anaerobic lagoons. Use of second stage lagoon effluent is preferable (lower odor) to primary lagoon effluent for irrigation. This also allows the primary lagoon to be operated in a near steady-state condition to maximize treatment efficiency. Sweeten (1991) indicates that aeration of lagoon liquid just prior to land application could reduce field odors.

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